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THE

MINERALOGICAL MAGAZINE

AND

Journal of

The Mineralogical Society.

INSTITUTED FEBRUARY 3, 1876.

EDITED BY L. J. SPENCER, M.A.

ASSISTED BY A COMMITTEE OF COUNCIL.

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1918.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 19, 1917, *at* 5 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

The deaths of Professor T. McKenny Hughes and Dr. G. C. Hoffmann, and the resignation of Mrs. S. Henson, were announced.

Mr. Albert Ernest Kitson was provisionally elected an Ordinary Member of the Society.

The following changes in the list of Officers and Council were approved for recommendation to the Members of the Society: Ordinary Members of Council—Messrs. Collins, De Castro, Hilton, and Russell in place of the four retiring Members of Council, Messrs. Evans, Hatch, Howe, and Campbell Smith.

A report was received from the sub-committee on abstracts for the Journal.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 19, 1917, *at* 5.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Fourteen Members were present.

The election of Mr. A. E. Kitson as an Ordinary Member of the Society was confirmed.

The following papers were read:—

1. On the problem of Sartorite: by Dr. G. F. Herbert Smith.
2. Note on a curious case of devitrification: by Dr. A. Scott.
3. The meteorites of Simondium, Eagle Station, and Amana: by Dr. G. T. Prior (p. 151).

A bottle of devitrified glass was exhibited in illustration of Dr. Scott's paper.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 6, 1917, *at* 5 *p.m.*

Dr. J. W. Evans, in the Chair.

The death of Dr. C. O. Trechmann was announced.

The following were selected as the dates of the meetings in 1918: Tuesdays, January 15, March 19, June 18, November 5 (Anniversary).

The draft Annual Report of Council, submitted by the Secretary, was read and approved.

A vote of thanks was passed to Dr. G. F. Herbert Smith for sending notices of the meetings of the Society to 'Nature' and other periodicals.

A proposal for the exchange of publications with 'Science Progress' was accepted.

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 6, 1917, *at* 5.30 *p.m.*

Dr. J. W. Evans, in the Chair.

Thirteen Members and six Visitors were present.

The Chairman nominated Messrs. Barrow and Crook to act as scrutineers of the voting-papers for the election of Officers and Council. The scrutineers reported that thirty-four voting-papers had been returned to the Secretary, and that the list as nominated by the Council was approved, namely:—

President. W. Barlow, F.R.S.

Vice-Presidents. Prof. H. L. Bowman, M.A., D.Sc., F.G.S.
A. Hutchinson, M.A., Ph.D., F.G.S.

Treasurer. Sir William P. Beale, Bart., K.C., M.P., F.G.S., F.C.S.

General Secretary. G. T. Prior, M.A., D.Sc., F.R.S.

Foreign Secretary. Prof. W. W. Watts, LL.D., Sc.D., F.R.S.

Editor of the Journal. E. J. Spencer, M.A., F.G.S.

Ordinary Members of Council.

T. V. Barker, M.A., B.Sc., F.C.S.
G. Barrow, F.G.S.
H. Collingridge, B.Sc., F.G.S.
H. F. Collins, A.R.S.M., M.I.M.M.
T. Crook, F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
J. P. De Castro, M.A., F.C.S.
Prof. H. Hilton, M.A., D.Sc.
F. P. Mennell, F.G.S.
Lieut. Arthur Russell.
G. F. Herbert Smith, M.A., D.Sc., F.G.S.
H. H. Thomas, M.A., Sc.D., F.G.S.

The following ANNUAL REPORT OF COUNCIL was read:—

During the Session 1916–17 four meetings have been held (by kind permission) in the Apartments of the Geological Society, Burlington House, W., at which fourteen papers were read. Two numbers of the Journal containing fourteen papers have been issued, viz. No. 83 published in November 1916, and No. 84 in June 1917.

At the Anniversary Meeting an addition was made to the Bye-laws to the effect that Trustees of the Society shall be *ex officio* Members of the Council.

The Society has been placed upon the Conjoint Board of Scientific Societies.

The balance-sheet of the year ending December 31, 1916, shows that the financial position of the Society continues to be satisfactory. The assets (exclusive of the Library and stock of the Journal) amounted to £939 2*s.* 6*d.*, and the liabilities to £13 17*s.* 1*d.* The value of the Stock invested in the names of the Trustees of the Society was on that date £778 18*s.* 6*d.*, corresponding to £15 17*s.* 11*d.* for each Life-Member. The investments of the Society have been transferred from the 4½ % to the new 5 % War Loan, and the amount invested has been brought up to a multiple of £50.

During the Session the Society has lost by death three Ordinary Members, Mr. A. K. Barnett, Prof. T. McKenny Hughes, and Dr. C. O. Trechmann, and by resignation two Ordinary Members, Mrs. Henson and Mr. J. B. Scrivener. Two Ordinary Members have been elected. The total number of Members on November 5, 1917, was 133, of whom fifteen are Honorary. Of the Ordinary Members forty-seven are Life-Members.

The Council has to congratulate the Society on its continued scientific activity and prosperity during the war.

On the motion of Dr. A. P. Young, seconded by Dr. Herbert Smith, the Report was adopted.

A vote of thanks to the Council of the Geological Society for permission to meet in the Apartments of the Society was carried.

The dates of meeting for 1918, proposed by the Council, were approved.

The following papers were then read:—

1. On etched crystals of Gypsum: by Miss E. Smith (communicated by Prof. Hilton).

2. On the mesosiderite-grahamite group of meteorites: by Dr. G. T. Prior (p. 151).

3. On changing the plane of a gnomonic or stereographic projection: by Prof. H. Hilton (p. 244).

4. On cleavage-angle in a random section of a crystal: by Prof. H. Hilton (p. 248).

SPECIAL COUNCIL MEETING.

Held at the Natural History Museum, South Kensington, January 7, 1918, at 3 p.m.

Mr. W. Barlow, F.R.S., President, in the Chair.

The following resolution, copies of which were sent to the First Commissioner of Works, the War Cabinet, 'The Times', and the Press Association, was passed:—

At a meeting of the Council of the Mineralogical Society of Great Britain and Ireland, held this day, it was resolved that the First Commissioner of Works and the War Cabinet be most earnestly requested to re-consider the proposal to utilize a portion or the whole of the Natural History Museum for other than its present purpose.

In particular, as regards the Mineral Department, the Mineralogical Society views with alarm any proposal to render inaccessible both to the general public and students and also to inquirers respecting economic questions the National Collection of Minerals, which has been accumulated during the past century and a half, and is now the largest and most complete in the world. This collection contains, for reference and comparison, examples of all minerals (and ores) that have been put to economic uses, representing numerous localities that have not yet been worked commercially. Direct reference to those parts of the collection not exhibited to the general public would supply a large amount of information, not available elsewhere, even in published works, respecting mineral occurrences in all parts of the world. Such information has been already utilized by the Advisory Council on Scientific and Industrial Research, by the War Office, and by the Department for the Development of Mineral Resources attached to the Ministry of Munitions of War, and could also be of use to the proposed Imperial Mineral Resources Bureau. The proposal to render such information inaccessible would seriously hamper the work of all Government Departments concerned with the development of the Mineral Resources of the Empire.

(Signed) Wm. Barlow, President, Mineralogical Society.
Wm. P. Beale, Hon. Treasurer, Mineralogical Society.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 15, 1918, *at* 5 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Mr. William Greswolde Williams Sandison was provisionally elected an Ordinary Member of the Society.

Messrs. A. Holmes and T. Crook were elected Auditors of the accounts for the year ending December 31, 1917.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 15, 1918, *at* 5.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Fourteen Members were present.

The election of Mr. W. G. W. Sandison as an Ordinary Member of the Society was confirmed.

The resolution protesting against the proposal to make use of the Natural History Museum for other Government Departments, passed at the Special Council Meeting held on January 7, 1918, was read.

The following papers were read :—

1. On rock-diagrams : by Dr. J. W. Evans.

2. The use of the gnomonic projection in the calculation of crystals: by Dr. G. F. Herbert Smith.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 19, 1918, *at* 5 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Mr. F. Barbason was provisionally elected an Ordinary Member of the Society.

The audited balance-sheet and statement of accounts for the year ending December 31, 1917, were approved, and the Secretary was

instructed to insert them in the Minutes and to publish them in the next number of the Journal.

The Editor was instructed to proceed with the preparation of a new number of the Journal, for which he reported he had sufficient material in hand.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 19, 1918, *at* 5.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Eleven Members and one Visitor were present.

The election of Mr. F. Barbason as an Ordinary Member of the Society was confirmed.

The following papers were read:—

1. On linear rock-diagrams: by Dr. J. W. Evans.

2. Lattice-like inclusions in Calcite from North Burgess, Ontario: by Prof. R. P. D. Graham (p. 252).

3. Graphical operations with four independent variables: by Prof. E. S. Fedorov.

MINERALOGICAL SOCIETY.

ABSTRACT OF RECEIPTS AND PAYMENTS FROM JANUARY 1 TO DECEMBER 31, 1917.

Receipts.	£ s. d.	£ s. d.
Balance from 1916—		
Bank (credit)	118 3 11	
Office (debit)	8 5	
		117 15 6
Subscriptions—(1) current	42 0 0	
(2) arrears	9 9 0	
(3) advance	2 2 0	
		53 11 0
Fees and Compositions		2 2 0
Sale of publications—		
By Publishers	20 15 6	
„ G. Savigar	1 13 0	
		22 8 6
Interest on Investments		40 18 5
		£236 15 5

Payments.	£ s. d.	£ s. d.
Printing Magazine (No. 83)	36 8 10	
Authors' copies	6 5 3	
Illustrations	7 19 6	
Extra War charge	8 14 0	
		59 7 7
Printing Magazine (No. 84)	22 4 5	
Authors' copies	5 9 2	
Illustrations	2 18 9	
Extra War charge	6 3 6	
		36 15 10
Reprints of Bye-laws and List of Members		1 13 0
Miscellaneous Printing (Williams & Strahan)		7 17 6
Editor's Honorarium (1916)		10 10 0
G. Savigar for care of Stock (1916)		1 1 0
Porter's Fee at meetings (1917)		1 0 0
Fee for manipulating lantern (1916)		1 0 0
Postage and Parcels—		
Magazine (1917)	5 17 8	
G. Savigar (1916)	6 11	
Hon. Secretary (1916)	8 6	
Hon. Treasurer (1916)	10 8	
		7 3 9
Donation to Conjoint Board of Scientific Societies		5 0 0
Broker's fee on conversion of Stock, &c.		15 0
Purchase of War Loan to make up £850		8 11 10
Balance at Bank	95 13 5	
At Office	6 6	
		95 19 11
		£236 15 5

Examined and compared with the vouchers, and found correct.
16 *March*, 1918.

(*Signed*) ARTHUR HOLMES
T. CROOK
} Auditors.

BALANCE SHEET.

DECEMBER 31, 1917.

LIABILITIES.	£	s.	d.
Owing for Editor's Honorarium (1917)	10	10	0
,, G. Savigar for care of stock of Publications (1917)	1	1	0
,, Do. for postage (1917)		3	3
,, Hon. Secretary for postage (1917)		7	11
,, Hon. Treasurer for postage (1917)		5	2
,, ,, ,, for printing reminders		6	6
,, fee for manipulating lantern (1917)		10	0
,, Williams & Strahan for miscellaneous printing	2	8	0
Excess of assets over liabilities	908	15	0
	£924	6	10

ASSETS.	£	s.	d.	£	s.	d.
Balance at Bank	95	13	5			
At Office		6	6			
				95	19	11
5 per cent. War Loan, £850 valued at				795	0	0
Sale of Publications (1917)—						
Owing from Publishers	15	7	11			
,, G. Savigar		2	0			
				15	9	11
Arrears of Subscriptions valued at				17	17	0
				£924	6	10

Number of Life Members, 45.

The stock of Publications and the value of the Library are not included in the above assets. (*Signed*) WM. P. BEALE,
Hon. Treasurer.
19 February, 1918.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 85. August, 1918. Vol. XVIII.

On the mesosiderite-grahamite group of Meteorites: with analyses of Vaca Muerta, Hainholz, Simondium, and Powder Mill Creek.[1]

By G. T. Prior, M.A., D.Sc., F.R.S.

Keeper of the Mineral Department of the British Museum.

[Read June 19, and November 6, 1917.]

In the Rose-Tschermak-Brezina classification of meteorites the intermediate class of stony-irons, in which iron and stony matter occur in approximately equal amounts and to which Maskelyne gave the name siderolites, is divided into (1) siderolites proper, including the groups of the pallasites and the siderophyres, and (2) lithosiderites, comprising the groups of the mesosiderites, grahamites, and lodranites. Mesosiderites are defined as consisting of iron and crystalline olivine and bronzite, and grahamites of the same constituents with the addition of plagioclase-felspar. As seen in the following pages, chemical and microscopic

[1] Communicated by permission of the Trustees of the British Museum.

examination of typical members of these two groups fails to reveal any real distinction between them based on the amount of felspar they contain. For the combined group, all the members of which contain abundant felspar, it is proposed to retain the earlier name of mesosiderite, which was first given to them by Rose.[1]

As pointed out in a previous paper,[2] from the author's point of view of a genetic relationship of meteorites, this group of mesosiderites is somewhat anomalous. The results of most of the published analyses showed that, although the nickeliferous iron and olivine had chemical compositions similar to those they have in the pallasites and thus served to place these meteorites in group A 2, the anorthite-felspar and the pyroxene, fairly rich in ferrous oxide, gave them a close relationship also to the eucrites and howardites of group A 5. Further analyses therefore of members of the group appeared to be desirable. The meteorites chosen for investigation were Vaca Muerta which has been classed as a grahamite, Hainholz a mesosiderite, and Simondium which presented many points of similarity with Hainholz.

Vaca Muerta (= Sierra de Chaco).

In Domeyko's original description of this meteorite[3] the locality was given as the Sierra de Chaco, but in a later communication[4] this was changed to the 'Quebrada (ravine) of Vaca Muerta, a dozen leagues from the small bay of Guanilla'. The uncertainty as to the precise place of fall has been discussed by L. Fletcher,[5] who gave reasons for supposing that specimens labelled as being from Taltal, Sierra de Chaco, Chili, Janacera (Jarquera) Pass, and Mejillones were all to be referred to Vaca Muerta. That these specimens all belong to one fall is most probably true, but some doubt must still remain as to whether the Vaca Muerta, 15 leagues to the south-east of Taltal, is the real place of fall. In view of this uncertainty, and for similar reasons to those advanced by

[1] G. Rose, Monatsber. Akad. Berlin, 1863, p. 34.

[2] G. T. Prior, On the genetic relationship and classification of meteorites. Mineralogical Magazine, 1916, vol. xviii, p. 35.

[3] I. Domeyko, Anal. Univers. d. Chili (Santiago), 1864, vol. xxv, p. 289.

[4] I. Domeyko, Compt. Rend. Acad. Sci. Paris, 1875, vol. lxxxi, p. 599.

[5] L. Fletcher, On the Meteorites which have been found in the Desert of Atacama and its neighbourhood. Mineralogical Magazine, 1889, vol. viii, p. 234.

Fletcher, Llano del Inca and Doña Inez should certainly be added to the above synonyms; for specimens of these meteorites in the British Museum Collection are under the microscope precisely similar to specimens of Vaca Muerta. These two meteorites were found by the Chilian and Bolivian Boundary Survey in 1888, and specimens which were obtained by the late Professor Henry A. Ward at Santiago in the following year were described by E. E. Howell, M. E. Wadsworth, A. C. Lane, and H. B. Patton.[1] In that paper Llano del Inca is stated to be about 35 leagues to the south-east of Taltal, and according to the maps Cerro de Doña Inez is also about 100 miles to the south-east of Taltal, so that the distance between the two localities cannot be very great. As in the case of many other Chilian meteorites, the specimens may have been transported to the place of find, which does not therefore represent the place of fall; and support to this idea is lent by Howell's remark (loc. cit., p. 95) that 'the breaking up of both meteorites . . . into such small, solid angular fragments with sharp corners . . . is doubtless the work of man'.

The following specimens in the British Museum Collection are referred to Vaca Muerta:

35124. A piece, weighing 493 grams, from 'Sierra de Chaco, Atacama Desert', presented in 1863 by W. Taylour Thomson, to whom it had been given by Domeyko.

46200. A piece, weighing 1850 grams, 'found 40 leagues inland near the low range of the Cordilleras of the Andes', obtained from F. Pini in 1873.

52234. A piece, weighing 551 grams, from 'Chili' (see L. Fletcher, loc. cit., p. 241), obtained from Mr. Cutter of London in 1879.

54721. A piece, weighing 4370 grams, from 'Desert of Atacama' (see L. Fletcher, loc. cit., p. 343), presented by F. A. Eck in 1882.

For the chemical analysis, a fragment weighing about 13 grams was taken from specimen 52234. The material was crushed in an iron mortar and was separated by the magnetic comb into an attracted portion weighing 5·7705 grams and an unattracted portion weighing 6·9030 grams. In order that the unattracted portion might be free from all but traces of metal, more than fifty separations were made with the magnetic comb in the fine powder left after the removal of the coarser pieces of iron. The results of the analyses are as follows:

[1] E. E. Howell, Proc. Rochester Acad. Sci., 1890, vol. i, p. 93.

	Attracted.	Unattracted.	Bulk-analysis.	
Fe	84·00	—	38·25	
Ni	6·38	—	2·90	41·51
Co	0·79	—	0·36	
Fe	0·07	2·38	1·37	
S	0·04	1·37	0·79	2·16
Fe	0·78*	1·62*	1·27	
Ni	0·41*	0·90	0·70	2·32
P	0·21	0·45	0·35	
SiO_2	0·90	45·47	26·02	
Al_2O_3	0·59	9·96	5·87	
Fe_2O_3	—	2·41	1·36	
Cr_2O_3	—	0·80	0·45	
FeO	—	12·48	7·03	
MnO	—	0·43	0·24	
CaO	0·83	7·04	4·35	
MgO	trace	13·07	7·36	
Na_2O	—	0·32	0·18	
H_2O	—	0·96	0·54	
Insoluble	4·11	—	—	
	99·11	99·66	99·39	

The analysis of the attracted shows that the ratio of Fe to Ni in the nickel-iron is about 13.

Separate analyses of the portions soluble and insoluble in hydrochloric acid of the unattracted material gave the following results:

	Soluble in HCl.	Molecular ratios.
SiO_2	12·15	0·202
Al_2O_3	8·76	0·086
FeO	1·42	0·020
MnO	—	
CaO	5·64	0·100
MgO	1·38	0·034
Troilite, Schreibersite, Fe_2O_3, H_2O	10·09†	
	39·44	

* These amounts are taken to correspond to the formula Fe_2NiP for schreibersite, but in the analysis of the unattracted, part of the phosphorus is probably in the form of phosphate, and thus the total amount of schreibersite may be over-estimated.

† From the analysis of the total unattracted portion.

	Insoluble in HCl (direct determinations).	Insoluble in HCl (by difference between total unattracted and soluble).	Molecular ratios.
SiO_2	33·22	33·32	0·555
Al_2O_3	1·15	1·20	0·012
Cr_2O_3	0·80*	0·80	0·005
FeO	11·38†	11·06	0·154
MnO	—	0·43	0·006
CaO	1·53†	1·40	0·025
MgO	11·64	11·69	0·292
Na_2O	0·32	0·32	0·005
	60·04	60·22	

These analyses show that the soluble portion consists mainly of anorthite with some troilite and only a little olivine; and the insoluble of a pyroxene (containing very little lime and having approximately the composition 2 $MgSiO_3$.$FeSiO_3$) and a little felspar which escaped decomposition by the acid. From the molecular ratios of the insoluble there would appear to be rather more silica than is required for the pyroxene and felspar, and the close agreement between the direct and indirect determinations seems to preclude the idea that this is due to errors in the analysis. The free silica thus indicated may possibly be present in the form of asmanite (tridymite) which is recorded by Tschermak as occurring in this meteorite,[1] although the author has not succeeded in identifying it with certainty in the thin slices in the British Museum Collection.

The amount of olivine in the sample analysed was so small, as shown by the low percentage of magnesia, that no reliable deduction as to its composition could be made from the analysis of the soluble part of the unattracted material. A separate analysis was therefore made of material broken from a patch of the mineral on the specimen. The result of the analysis, made on 0·5583 gram of material, is as follows:

		Molecular ratios.
SiO_2	39·89	0·665
FeO	8·98	0·125
MgO	49·50	1·237
Insoluble	1·95	
	100·32	

The olivine, therefore, has approximately the composition

$$10\,Mg_2SiO_4.Fe_2SiO_4.$$

* From the analysis of the total unattracted portion.

† Including some MnO.

[1] G. Tschermak, Sitzungsber. Akad. Wiss. Wien, 1884, vol. lxxxviii, (1), p. 352.

The approximate mineral composition of the meteorite deduced from the analyses is as follows:

Nickel-iron	... ...	$41\frac{1}{2}$ (in which Fe : Ni is about 13).
Troilite	... ...	2
Anorthite	... ...	17
Pyroxene	... ...	32 (in which MgO : FeO is about 2).
Olivine	... ...	$1\frac{1}{2}$ (in which MgO : FeO is about 10).
Chromite	... ...	1
Rust	... ...	2
Schreibersite, &c.	...	3
		100

Analyses of specimens referable to Vaca Muerta have been made by I. Domeyko on one of the original specimens of Vaca Muerta[1]; by C. A. Joy on a specimen from the 'Janacera' (really Jarquera) Pass, 50 miles S.E. of Copiapo[2]; by J. M. Davison on a specimen of Doña Inez[3]; and by L. G. Eakins on a specimen of Llano del Inca.[4] The numbers given in these analyses, except the last two, are not easily interpreted in terms of the mineral contents of the meteorite. Domeyko appears to have been unaware of the presence of felspar, while Joy, on the other hand, concluded that the silicate portion consisted mainly of felspar with some olivine but no pyroxene. Domeyko, Joy, and Eakins agree fairly closely as regards the composition of the nickel-iron in making the ratio of Fe to Ni about 10.

The results of Eakins's analyses of the soluble and insoluble parts of the stony matter of Llano del Inca are as follows:

	Soluble.	Molecular ratios.		Insoluble.	Molecular ratios.
SiO_2	28·08	0·47	SiO_2	53·11	0·88
Al_2O_3	12·74	0·12	Al_2O_3	2·32	0·02
FeO	42·52	0·59	Cr_2O_3	0·90	—
NiO	2·90	0·04	FeO	18·82	0·26
MnO	0·20	—	CaO	1·75	0·03
CaO	9·33	0·16	MgO	23·10	0·58
MgO	1·98	0·05		100·00	
P_2O_5	2·25	—			
	100·00				

[1] I. Domeyko, Compt. Rend. Acad. Sci. Paris, 1864, vol. lviii, p. 551.
[2] C. A. Joy, Amer. Journ. Sci., 1864, ser. 2, vol. xxxvii, p. 243.
[3] E. E. Howell, Proc. Rochester Acad. Sci., 1890, vol. i, p. 93.
[4] Ibid., p. 94.

The numbers obtained for the soluble portion suggest that the greater part consists of oxides of iron and nickel from the rusting of the meteorite, together with anorthite and only a little olivine. The molecular ratios for the insoluble portion correspond quite closely to 58 $MgSiO_3$. 26 $FeSiO_3$. $CaSiO_3$ + 2 $CaAl_2Si_2O_8$, i. e. (as in the analysis of the British Museum specimen) to a pyroxene in which the ratio of MgO to FeO is about 2, together with a little felspar which has escaped decomposition.

Davison's analysis of the total mass of Doña Inez is as follows:

			Molecular ratios.	
SiO_2	...	18·41	...	0·30
FeO	...	58·91	...	0·82
Al_2O_3	...	6·39	...	0·06
P_2O_5	...	0·32	...	—
NiO	...	5·28	...	0·07
CoO	...	0·34	...	—
CaO	...	3·56	...	0·06
MgO	...	4·92	...	0·12
S	...	1·06	...	0·03
Cu	...	trace		
		99·24		

The molecular ratios correspond fairly closely with $6\frac{1}{2}$ $CaAl_2Si_2O_8$ + 112 $MgSiO_3$. 6 $FeSiO_3$ + 3 FeS + 7 $Fe_{10}Ni$ (oxidized), i. e. to a mixture of oxidized nickel-iron in which the ratio of Fe to Ni is about 10, a pyroxene in which again the ratio of MgO to FeO is about 2, anorthite, and some troilite. The numbers he obtained for the soluble and insoluble parts are not so readily interpreted in terms of the minerals present.

Under the microscope, thin sections of Vaca Muerta (35124 and 46200), Llano del Inca (66206), and Doña Inez (66203) in the British Museum Collection are indistinguishable from each other. They all show a marked cataclastic structure, for the anorthite-felspar occurs only in sharp-edged broken fragments and the pyroxene shows little in the way of crystal outline. The iron is present for the most part as an irregular net-work enclosing felspars and pyroxene, and was obviously the last constituent to consolidate. The pyroxene is mainly bronzite giving straight extinction, but with this orthorhombic pyroxene are some grains with oblique extinction: there appears to be no reason, however, for supposing any of it to be of the nature of diallage, as suggested by Lane (loc. cit., p. 96). Olivine is not to be detected with certainty except in the

case of one fairly large rounded section in one of the slides of Vaca Muerta. In the actual specimens of the meteorite olivine is seen rather sparsely distributed but occasionally in fairly large patches.

Hainholz.

This meteorite was found near Minden, in Westphalia, in 1856, was first described by Wöhler[1] in 1857, and was analysed by C. Rammelsberg[2] in 1870. According to his analysis it consisted of nickel-iron in which the ratio of Fe to Ni was about 10, and of soluble and insoluble silicates in both of which the ratio of MgO to FeO was about 3. He appears to have completely overlooked the presence of felspar and makes no record of any Al_2O_3 or CaO in his analysis of the soluble silicates. A determination of the composition of the nickel-iron, made by E. Priwoznik,[3] in 1892, gave a ratio of Fe to Ni of about 13, as in Vaca Muerta.

For the present analysis a piece weighing about 17 grams was taken from a specimen (33911) in the British Museum Collection, which had been obtained from Dr. A. Krantz in 1862. It was separated by the magnet into an attracted portion weighing 9·1269 grams and an unattracted portion weighing 8·3268 grams. The results of the analyses are as follows:

	Attracted.		Unattracted.	Bulk-analysis.[4]	
	(1)	(2)			
Fe	78·74	83·65	—	42·13	46·54
Ni	7·48	7·83	—	4·00	
Co	(0·76)*	0·80	—	0·41	
Fe	—	—	4·99	2·52	3·96
S	—	—	2·86	1·44	
Fe	0·67†	—	—	0·36	0·69
Ni	0·43†	—	—	0·23	
P	0·19	trace	—	0·10	

[1] F. Wöhler, Ann. Phys. Chem. (Poggendorff), 1857, vol. c, p. 342.

[2] C. Rammelsberg, Monatsber. Berlin. Akad. 1870, p. 322.

[3] E. Priwoznik, Österr. Zeits. Berg- u. Hüttenwesen, 1892, No. 39.

[4] In the calculation of the bulk-analysis, analysis (1) of the attracted, with the loss evenly distributed over the constituents, was used.

* Calculated from result in (2).

† The amounts of Fe and Ni are taken to correspond to the formula Fe_2NiP for schreibersite.

	Attracted. (1)	Attracted. (2)	Unattracted.	Bulk-analysis.
SiO_2 ...	2·05	1·07	40·73	21·69
Al_2O_3 ...	0·91	0·67	8·89	4·99
Fe_2O_3 ...	—	—	5·48	2·77
Cr_2O_3 ...	—	—	0·65	0·33
FeO ...	—	—	12·24	6·19
MnO ...	—	—	trace	trace
NiO ...	—	—	0·95*	0·48
CaO ...	1·04	0·58	5·80	3·49
MgO ...	trace	trace	13·98	7·07
P_2O_5 ...	—	—	0·67*	0·34
Na_2O ...	—	—	0·42	0·21
H_2O ...	—	—	2·38	1·20
Insoluble	5·46	4·32	—	—
O, C, &c.	(2·27)	(1·08)	—	—
	100·00	100·00	100·04	99·95

Analysis (1) of the attracted was made on the original material from the 17 gram piece. The low summation is probably partly due to loss owing to spurting during the solution of the metal in aqua regia and the subsequent expulsion of nitric acid by evaporation. Analysis (2) was made on another fragment of the meteorite weighing about 5 grams, which was separated by the magnet into 2·3081 grams of attracted and 2·7169 of unattracted. In this analysis there is still a low summation, although every precaution was taken to avoid any loss. Low summation, in the author's experience, occurs almost invariably in the analysis of the attracted portion of meteorites, and may be due to the non-determination of some volatile constituent or of carbonaceous matter. In the present case it may be partly attributed to oxygen, as the iron was rather rusted.

The numbers given under the unattracted are the combined result of separate analyses of the portions soluble and insoluble in hydrochloric acid, the individual numbers for which are as follows:

* The Ni and P are taken as oxidized, since in the analysis of the soluble below there is no excess of Fe beyond that determined as Fe_2O_3 to form schreibersite.

	Soluble.	Molecular ratios.	Insoluble.	Molecular ratios.
SiO_2 ...	10·91	0·18	29·82	0·50
Al_2O_3 ...	7·37	0·07	1·52	0·015
Fe_2O_3 ...	5·48*	—	—	—
Cr_2O_3 ...	—	—	0·65*	0·004
FeO ...	0·58	—	11·66	0·16
MnO ...	—	—	trace	—
NiO ...	0·95	—	—	—
CaO ...	4·73	0·08	1·07	0·02
MgO ...	1·77	0·04	12·21	0·30
Na_2O ...	—	—	0·42*	0·007
P_2O_5 ...	0·67*			
H_2O ...	2·38*			
Fe ...	4·99			
S ...	2·86*			
	42·69		56·93	

The analyses show that, as in the case of Vaca Muerta, the nickel-iron is poor in nickel, but with a ratio of Fe to Ni of about $10\frac{1}{2}$ rather less than in the Chilian meteorite; that the soluble portion of the stony material consists of anorthite, with some troilite and rust, and only a little olivine; and that the insoluble is mainly composed of a pyroxene, poor in lime, in which the ratio of the MgO to FeO is again about 2, together with a little chromite and undecomposed felspar.

Since in the case of this meteorite also no reliable deduction could be drawn as to the composition of the small amount of olivine in the soluble portion of the unattracted material, a separate analysis was made on material taken from a small patch of the mineral on the specimen. The result of the analysis, made on only 0·1087 gram of material, is as follows:

		Molecular ratios.
SiO_2 ...	40·48	0·67
FeO ...	11·59	0·16
MgO ...	42·97	1·07
Insoluble ...	2·76	
Loss and O ...	(2·20)	
	100·00	

* These determinations were made on separate portions of the total unattracted.

The ratio of MgO to FeO in the olivine is therefore between 6 and 7, perhaps nearer 7 than 6, since the material was slightly oxidized. The lower ratio as compared with Vaca Muerta corresponds to the lower ratio of the Fe to Ni in the nickel-iron.

The approximate mineral composition of the meteorite, deduced from the analyses, is as follows:

Nickel-iron	...	$46\frac{1}{2}$ (in which Fe : Ni is about $10\frac{1}{2}$)
Troilite		4
Anorthite		$14\frac{1}{2}$
Pyroxene		27 (in which MgO : FeO is about 2)
Olivine		$1\frac{1}{2}$ (in which MgO : FeO is about 7)
Chromite		$\frac{1}{2}$
Rust		4
Schreibersite, &c.		2
		100·0

Hainholz, a typical mesosiderite, is thus seen to have a chemical and mineral composition very similar to that of the grahamite Vaca Muerta, from which certainly it cannot be distinguished as regards the amount of felspar.

Under the microscope in a thin section of the British Museum specimen the structure is seen to be finer grained and less cataclastic than that of Vaca Muerta, for the felspar occurs more in laths and less as broken fragments, although a few of these are prominent in the slide[1]; it is in fact much more basaltic in character and thus strikingly resembles that of the meteorite Simondium described below. The section shows one rounded olivine precisely similar to the one in the section of Vaca Muerta. The iron occurs in more detached grains.

Simondium.

A short description of this meteorite, which was found in gravel near Simondium Station on the Paarl to French Hoek line, Cape Colony, has been previously given by the author.[2] It has unusual characters and resembles in some parts a terrestrial basalt perhaps more closely than any other meteorite (see loc. cit., Plate VII). As it contained olivine as well as bronzite and plagioclase-felspar and in some parts only little nickel-iron, it was referred to the howardite group. In many respects,

[1] See G. Tschermak, 'Die mikroskopische Beschaffenheit der Meteoriten,' 1883–1885, p. 22 and pl. XXIV, fig. 4.

[2] G. T. Prior, Mineralogical Magazine, 1910, vol. xv, p. 312.

however, it differed from any member of that group, for some fragments contained nodules of troilite and olivine up to 2 inches in length, while others showed fairly plentifully distributed grains of nickel-iron. As the meteorite was in such a bad state of oxidation, no attempt was made in 1910 to analyse it as a whole, but an analysis was made of the olivine which showed that its chemical composition was similar to that of the olivine in most pallasites, for the ratio of MgO to FeO was as high as 10, instead of about 2 as it is in the olivine of the howardites, Luotolacs and Mässing.

The meteorite therefore presents, from the author's point of view, a similar anomalous composition to that of the mesosiderites, and, in spite of its altered condition, a chemical analysis which might lead to a determination, at any rate, of the composition of the pyroxenic constituent, seemed desirable. For this purpose a fragment weighing about 9 grams was taken from the interior of one of the specimens (1909, 149) which, from its colour, appeared to be less oxidized than the rest, although, as seen in thin section under the microscope, even in this part the nickel-iron was mainly represented by red and black alteration products. From the powdered fragment 0·5533 gram of black attracted material was separated by the magnet from 8·4658 grams of unattracted. The results of the analyses are as follows:

	Attracted.	Unattracted.
Fe	47·76	—
Ni	3·18	—
Co	undetd.	—
Fe	—	1·63
S	—	0·93
SiO_2	9·65	39·36
Al_2O_3	2·40	7·10
Cr_2O_3	—	0·78
Fe_2O_3	—	5·22
FeO	—	10·30
NiO	—	5·02
MnO	—	trace
CaO	0·61	2·51
MgO	0·24	13·14
Na_2O	—	0·10
H_2O	—	10·77
P_2O_5	—	0·85
SO_3	—	2·71
Insoluble	7·92	
S, O, &c.	(28·24)	
	100·00	100·42

The figures given under the unattracted are the combined result of separate analyses of the portion soluble in water, and, after its separation of the portions soluble and insoluble in hydrochloric acid. The results of these three analyses are as follows:

	Soluble in water.	Molecular ratios.
NiO	1·28	... ... 0·017
CaO	0·91	... ... 0·017
SO_3	2·71	... ... 0·034
H_2O	undet.	
	4·90	

	Soluble in HCl.	Molecular ratios.	Insoluble in HCl.	Molecular ratios.
SiO_2 ...	11·23	... 0·19	... 28·13	... 0·47
Al_2O_3 ...	5·47	... 0·05	... 1·63	... 0·015
Cr_2O_3 ...	—	... —	... 0·78*	... 0·005
Fe_2O_3 ...	5·22*	... 0·03	... —	... —
FeO ...	1·38	... 0·02	... 8·92	... 0·13
NiO ...	3·74	... 0·05	... —	... —
MnO ...	—	... —	... trace	... —
CaO ...	0·72	... 0·013	... 0·88	... 0·015
MgO ...	1·44	... 0·036	... 11·70	... 0·29
Fe ...	1·63	... 0·03	... —	
S ...	0·93*	... 0·03	... —	
Na_2O ...	—	... —	... 0·10*	
P_2O_5 ...	0·85*	... 0·006	... —	
H_2O ...	10·77*	... —	... —	
	43·38		52·14	

From the results of the analyses the following conclusions may be drawn:

(1) In the small attracted portion the iron and nickel are almost wholly in the oxidized condition, but the original nickel-iron was one poor in nickel with a ratio of Fe to Ni well above 10, as in most of the pallasites.

(2) The part of the unattracted soluble in water consists of hydrated sulphates of lime and nickel. The presence of sulphate of lime in the part soluble in water of a meteorite has been often, though perhaps somewhat rashly, supposed to indicate the original presence of oldhamite.

* These determinations were made on separate portions of the total unattracted material. A large amount of the H_2O is to be referred to the part of the unattracted soluble in water.

In the present case it has resulted almost undoubtedly from the decomposition of troilite and felspar.

(3) After the removal of the part soluble in water, the portion of the unattracted soluble in hydrochloric acid is made up partly of some anorthite and troilite and a little olivine, but mainly of decomposition products consisting of hydrated oxides and silicates of iron, aluminium, and nickel.

(4) The part of the unattracted insoluble in hydrochloric acid consists mainly of a pyroxene in which the ratio of MgO to FeO is about 2 as in the mesosiderites, together with a little chromite and felspar.

There is little doubt that the original constituents of the meteorite were mainly anorthite, pyroxene, nickel-iron, and olivine, all having chemical compositions very similar to those of the same minerals in Vaca Muerta and Hainholz. In the few fragments of Simondium which have been preserved the iron has been for the most part oxidized, so that they present very much the same appearance as the rusted specimens of Doña Inez and Llano del Inca. That in parts of the meteorite the amount of nickel-iron was much more plentiful and conspicuous than in the much weathered and oxidized fragments in the British Museum Collection seems probable from the fact that the large stones, a foot in diameter, originally discovered, were broken up by the finders, as in the case of many Chilian meteorites, under the mistaken idea that the metal was silver.

The three meteorites, Vaca Muerta (including Llano del Inca and Doña Inez), Hainholz, and Simondium thus present such similar characters that they must all be referred to the same group, to which the earlier name of mesosiderite is given. In the case of Vaca Muerta and Hainholz any distinction between mesosiderite and grahamite as regards the amount of felspar breaks down altogether. Examination of the microscopic characters and consideration of the analyses which have been published of other members of this group, as described below, indicate that all have very similar characters to those of Vaca Muerta and Hainholz, and that in their case also no real distinction as regards the amount of felspar can be drawn between them.

Taney County (= Mincy).

This meteorite, which is reported to have fallen in Taney Co., Missouri, in 1857, was first analysed by Lawrence Smith[1] in 1865

[1] J. L. Smith, Amer. Journ. Sci., 1865, ser. 2, vol. xl, p. 213.

under the name of Newton County, Arkansas (to which place a fragment had been transported), and later in 1887 by J. E. Whitfield[1] under the name of Mincy.

Lawrence Smith determined the compositions of the nickel-iron, the olivine, and the pyroxene (so-called 'hornblende') separated mechanically from the meteorite, and was quite unaware of the presence of felspar. According to his analyses, the ratio of Fe to Ni in the nickel-iron is about $12\frac{1}{2}$, and the ratio of MgO to FeO in the olivine about 7, and in the pyroxene about 3. These three constituents therefore have chemical compositions very similar to those of the same minerals in Vaca Muerta.

Whitfield's analyses were made on the nickel-iron, the total stony matter from which the iron had been separated, and the portion of the stony matter insoluble in hydrochloric acid, and by them the presence of abundant anorthite in the meteorite is made very evident. For the nickel-iron he obtained a ratio of Fe to Ni of about 9. His results for the stony matter are as follows:

	Total stony matter.	Molecular ratios.	Insoluble in HCl.	Molecular ratios.
SiO_2 ...	45·88	0·76	52·39	0·87
Al_2O_3 ...	7·89	0·08	7·11	0·07
FeO ...	19·73	0·27	14·68	0·20
CaO ...	6·02	0·10	4·49	0·08
MgO ...	17·96	0·45	21·33	0·53
NiS ...	1·67	0·02	—	
FeS ...	0·54	0·01	—	
	99·69		100·00	

The molecular ratios of the insoluble correspond very closely to a mixture of 53 $MgSiO_3$. 20 $FeSiO_3$. 2 $CaSiO_3$ and 7 $CaAl_2Si_2O_8$, i. e. of a pyroxene in which the ratio of MgO to FeO is about 2, as in Vaca Muerta, and some anorthite. Making use of this composition of the pyroxene in the interpretation of the results of the analysis of the total stony matter, the molecular ratios are seen to correspond fairly closely to a mixture of the molecules

$$42\ MgSiO_3 . 16\ FeSiO_3 . 2\ CaSiO_3 + 8\ CaAl_2Si_2O_8$$

(i.e. of pyroxene and anorthite), together with some FeS, only a very little olivine, and oxides of Fe and Ni either from rusted nickel-iron or from nickel-iron which had not been separated from the

[1] J. E. Whitfield, Amer. Journ. Sci., 1887, ser. 3, vol. xxxiv, p. 467.

stony matter, for it is improbable that any of the nickel is in the form of sulphide as given in the analysis.[1]

Under the microscope a thin section of a specimen (40886) in the British Museum Collection shows a structure much less cataclastic than that of Vaca Muerta but coarser grained than that of Hainholz. The pyroxene occurs in rounded grains forming a sort of mosaic with the interstices filled with bladed felspar: this was obviously the last mineral to consolidate before the nickel-iron, which occurs in strings enclosing felspar and pyroxene.

Thus neither chemical analysis nor microscopic examination suggests any reason why this meteorite as regards the amount of felspar should have been classed as a 'mesosiderite' rather than a 'grahamite'.

Estherville.

This meteorite, of which several large masses and many small fragments fell in Emmet Co., Iowa, on May 10, 1879, has been analysed by Lawrence Smith.[2] As in the case of Taney County, separate analyses were made of the nickel-iron, olivine, and pyroxene, picked out from the crushed meteorite, and the presence of felspar was again undetected, although it had been already recorded by C. U. Shepard.[3] The analyses show that the chemical compositions of these constituents are very similar to those in Vaca Muerta, the ratio of Fe to Ni in the nickel-iron being about 13, the ratio of MgO to FeO in the olivine about 6, and in the pyroxene about 2.

In later accounts of the meteorite the presence of felspar is mentioned by Tschermak,[4] Wadsworth,[5] and Meunier.[6]

Under the microscope thin sections prepared from specimens (53764 and 65575) of the meteorite in the British Museum Collection show abundant anorthite-felspar, not only as groundmass as in Taney County, but also as broken sharp-edged fragments, intermixed with rounded grains and larger sections of pyroxene, most of which give straight

[1] There is no justification for G. P. Merrill's suggestion (see Handbook and Descriptive Catalogue of the Meteorite Collections in the United States National Museum. U.S. Nat. Mus. Bull. 94, 1916, p. 106) that in Kunz's original description the analyses of the soluble and insoluble were reversed.

[2] J. L. Smith, Amer. Journ. Sci., 1880, ser. 3, vol. xix, p. 459.

[3] C. U. Shepard, Amer. Journ. Sci., 1879, ser. 3, vol. xviii, p. 188.

[4] G. Tschermak, 'Die mikroskopische Beschaffenheit der Meteoriten,' 1883–1885, pp. 22 and 23, pl. XXIV. fig. 1.

[5] M. E. Wadsworth, 'Lithological Studies,' 1884, pp. 92–101.

[6] S. Meunier, 'Révision des Lithosidérites,' 1895, pp. 30–32.

extinction, but some oblique. In the two slides only three rounded sections could be doubtfully referred to olivine.

Estherville, therefore, as regards its constituents and their chemical compositions, differs in no way from the other previously described members of the group of mesosiderites. The fact that the felspar, which is seen so prominently in thin sections, was originally overlooked, doubtless accounts for the meteorite having been classed as a 'mesosiderite' instead of a 'grahamite'.

Powder Mill Creek (= Rockwood = Crab Orchard).

This meteorite, which was found in Cumberland Co., Tennessee, in 1887, was analysed by J. E. Whitfield,[1] and described by G. F. Kunz[2] in the same year. The analysis by Whitfield of the stony material is difficult to interpret in terms of the constituents since he was unable to make separate determinations of the soluble and insoluble portions. He states, however, that the soluble contained only traces of MgO, and concludes from this the absence of olivine. A separate analysis of a nodule, containing only about 6 per cent. of soluble material, gave a ratio of MgO to FeO of about 3. The composition of the pyroxene is, therefore, not very different from that in Vaca Muerta. In the nickel-iron the ratio of Fe to Ni was found to be about 7, and is thus rather low for an iron showing such coarse octahedral structure as is figured (loc. cit., p. 388), but the material analysed may have been a small exceptional piece not typical of the main mass. A re-determination of the composition of the nickel-iron therefore seemed desirable. Accordingly a fragment weighing about 11 grams from the specimen (63547) of the meteorite in the British Museum Collection was crushed and separated by the magnet into an attracted portion weighing 6·0186 grams and an unattracted portion weighing 4·6306 grams. The result of an analysis of the attracted portion is as follows:

Fe	73·15
Ni	5·61
Insoluble	11·58
Anorthite, &c.	(9·66)
	100·00

[1] J. E. Whitfield, Amer. Journ. Sci., 1887, ser. 3, vol. xxxiv, p. 387.
[2] G. F. Kunz, ibid., p. 476.

The soluble material besides the nickeliferous iron consisted mainly of anorthite, for only traces of MgO and S were found.

The analysis shows that the fragment contained about 42 per cent. of nickel-iron in which the ratio of Fe to Ni is about 13, as in Vaca Muerta.

Although olivine may not be present in many samples of the meteorite, on a polished slice it is seen to occur sparsely distributed just as it does in other mesosiderites. As its composition has not hitherto been determined, an analysis was made of material picked out from a patch of the mineral on the slice (63547) of the meteorite in the British Museum Collection. The result of the analysis is as follows:

		Molecular ratios.
SiO_2	40·18	0·666
FeO	9·15	0·127
MgO	48·91	1·213
Insoluble (Chromite)	1·42	
	99·66	

The composition of the olivine corresponds approximately to the formula $10\,Mg_2SiO_4 . Fe_2SiO_4$, as in Vaca Muerta. The insoluble proved to consist mainly of chromite, probably from inclusions in the olivine.

Now the analysis by Whitfield of the nodule referred to on p. 167 gave the following result:

		Molecular ratios.
SiO_2	49·96	0·83
Al_2O_3	4·75	0·045
FeO	15·97	0·22
CoO + NiO	trace	—
CaO	1·15	0·02
MgO	28·15	0·70

The fact that the amount of silica is too low in order to form only metasilicates with the bases suggests that olivine is present. By introducing the composition of the olivine as determined above the molecular ratios correspond approximately to the following:

$$44\,MgSiO_3 . 20\,FeSiO_3 + 13\,Mg_2SiO_4 . 1\tfrac{1}{3}\,Fe_2SiO_4 + 3\,CaAl_2Si_2O_8,$$

i. e. to a mixture of pyroxene in which the ratio of MgO to FeO is about 2 with olivine in which this ratio is about 10, and a little anorthite.

A thin section of the British Museum specimen shows a sharp division into two parts, one of which contains much iron while the other is free from it. The latter part consists of a coarse-grained mosaic of anorthite and pyroxene just like a gabbro, and the other part of much

iron with anorthite and pyroxene broken into irregular fragments. This slide apparently gives a picture in miniature of what has happened in the main mass of this and other mesosiderites, viz. the invasion and breaking up of a pyroxene-anorthite rock by nickeliferous iron (see p. 171).

The results of analyses and microscopic examination show that, in chemical and mineral composition, Powder Mill Creek is very similar to other mesosiderites.

Morristown (= Hamblen County).

This meteorite, which was found in September, 1887, in Hamblen Co., Tennessee, has been analysed by L. G. Eakins[1] and described by G. P. Merrill.[2] According to Eakins's analysis, in the nickel-iron the ratio of Fe to Ni is about 12, as in Vaca Muerta. His results for the soluble and insoluble portions of the stony material are as follows:

	Soluble in HCl.	Molecular ratios.	Insoluble in HCl.	Molecular ratios.
SiO_2 ...	45·61	0·76	50·67	0·84
Al_2O_3 ...	22·62	0·22	14·89	0·15
Cr_2O_3 ...	—	—	1·32	0·01
FeO ...	11·73	0·16	10·55	0·15
MnO ...	—	—	0·76	0·01
NiO ...	1·06	0·01	—	—
CaO ...	14·09	0·25	3·61	0·07
MgO ...	3·64	0·09	17·98	0·45
K_2O ...	—	—	0·08	—
Na_2O ...	—	—	0·19	—
P_2O_5 ...	1·25	0·01	—	—
	100·00		100·00	

These analyses are difficult to interpret in terms of the constituent minerals. The soluble, however, as in other analyses of mesosiderites, appears to consist mainly of anorthite, with only a little olivine, most of the oxide of iron and nickel being derived probably either from rust or from nickel-iron and troilite not separated from the stony material. In the insoluble the ratio of MgO to FeO is about 3.

The microscopic characters of the meteorite have been well described by Merrill. He states that the felspar occurs, as in other members of the group, in broken fragments, and that the structure is strongly ataclastic, not like that of a clastic rock, but rather of a crystalline variety which had been subjected to dynamic agencies. Olivine was not

[1] L. G. Eakins, Amer. Journ. Sci., 1893, ser. 3, vol. xlvi, p. 283.
[2] G. P. Merrill, Amer. Journ .Sci., 1896, ser. 4, vol. v, p. 149.

detected with certainty. Two pyroxenes were distinguished, one cloudy with inclusions and giving straight extinctions, the other clear and pellucid and giving oblique extinctions as high as 30°.

In a thin section from the specimen (81008) in the British Museum Collection the two pyroxenes are not easily distinguishable in appearance: most sections which are fairly clear give straight extinctions, but a few occur with oblique extinctions. There appears to be no reason for supposing the latter to be diallage-like, as suggested by Merrill, whose micro-chemical test for alumina is not very convincing considering the intimate association of the mineral with anorthite. In the author's experience, in no analysis of a meteorite has he found it necessary to attribute any alumina to a pyroxenic constituent. In parts of the slide the pyroxene occurs in irregular ophitic-like patches enclosing the broken felspars. One fairly large section in the slide may be doubtfully referred to olivine. In a polished slice of the meteorite a few small patches of brown olivine are visible, but they did not afford sufficient material for analysis.

Conclusions.

The results of the analyses of the preceding members of the mesosiderite group of meteorites may be summarized in the following table, which is a corrected form of that given in a previous paper: [1]

Mesosiderites.

Name.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in olivine.	Ratio of MgO to FeO in pyroxene.	Analyst and date.
Vaca Muerta (including Llano del Inca and Doña Inez)	13	10	2	G. T. Prior, 1918.
Hainholz	10½	7	2	,,
Simondium	over 10	10	2	,,
Taney County	12½	7	3	J. L. Smith, 1865.
Estherville	13	6	2	,, 1880.
Powder Mill Creek	13	10	2	J. E. Whitfield, 1887, and G. T. Prior, 1918.
Morristown	12	—	3	L. G. Eakins, 1893.

[1] G. T. Prior, Mineralogical Magazine, 1916, vol. xviii, pp. 34-35.

The preceding investigation has shown that no real distinction can be drawn between so-called 'mesosiderites' and 'grahamites' as regards the amount of felspar they contain. For the combined group the earlier name mesosiderite is proposed.

The members of this group are remarkably uniform in character. They consist mainly of pyroxene and felspar, with nickel-iron in large amount but rather unevenly distributed, and nodules of olivine somewhat sparsely distributed but occasionally of considerable size. Accessory constituents are troilite, chromite, and schreibersite. The felspar is nearly pure anorthite; the pyroxene is fairly rich in ferrous oxide with a ratio of MgO to FeO about 2; the olivine, on the other hand, is poor in ferrous oxide with a ratio of MgO to FeO from 6 to 10; and the nickel-iron is poor in nickel with a ratio of Fe to Ni from 10 to 13. The curiously uneven distribution of the iron and the rather sporadic occurrence of the olivine suggest that both these constituents are in some way foreign to the main mass of stony matter consisting of anorthite and pyroxene, and to this idea the peculiar structural features of these meteorites lends support. In structure, in the parts rich in iron, they are highly cataclastic, the felspars occurring in sharp-edged broken fragments. In the parts freer from iron, however, this cataclastic structure is less apparent, and sometimes, as in Powder Mill Creek, the stony matter consists of a granular aggregate of anorthite and pyroxene like a gabbro, or, as in Hainholz and Simondium, it shows a more basaltic character with the felspar in laths. In this connexion Merrill's description of the structure of Morristown (loc. cit., p. 153) may be noted. He says, 'The coarser portions of the rock, and particularly those in immediate juxtaposition with the metallic iron, have a strongly marked cataclastic structure, the felspars existing mainly as angular fragments. . . . All structural features point to the injection of the metallic iron, or at least to its reduction to the metallic state, subsequently to the solidification of the stone, the same being accompanied by a shattering and more or less displacement of the minerals in the near vicinity. In the more siliceous portions the iron exists only in small blebs, and seems to have been wholly without effect on the structural features; but where existing in masses of some size . . . the appearance is at once suggestive of subsequent injection and consequent disruption of articles'.

From the author's point of view of a genetic relationship of meteorites, therefore, there is considerable a priori evidence in favour of the idea

that the characters of this group of meteorites may be most reasonably explained as the result of a mixture of two types, to one of which belong the pyroxene and anorthite, and to the other the iron and olivine; a eucritic magma, i.e. according to the theory, one of higher oxidation, having been invaded by a pallasitic magma, i.e. by a, terrestrially speaking, more 'deep-seated' one of lower oxidation.

On the chemical composition of the Meteorites Amana (= Homestead) and Eagle Station.[1]

By G. T. Prior, M.A., D.Sc., F.R.S.
Keeper of the Mineral Department of the British Museum.

[Read June 19, 1917.]

Amana.

THE Amana meteorite, known also as Iowa County, Homestead, and West Liberty, is fully described in O. C. Farrington's 'Catalogue of the Meteorites of North America'.[2] After the appearance of a brilliant meteor which on the night of February 12, 1875, passed with loud detonations from S.W. to N.E. over northern Missouri and southern Iowa, about 100 meteoric stones, weighing altogether some 500 lb., were found scattered over an elliptic area of about eighteen square miles from Amana in Amana township to Boltonville in Iowa township, both in Iowa Co., Iowa. In the same year three analyses were made of the meteorite by G. D. Hinrichs[3] and J. Lawrence Smith[4] in the United States, and by C. W. Gümbel and A. Schwager[5] in Germany. All three analyses, the results of which are given on p. 175, agree in making both olivine and pyroxene rich in ferrous oxide. To accord with the idea of a genetic relationship of meteorites advanced by the author in a previous paper,[6] this low ratio of MgO to FeO in the ferro-magnesian silicates should be associated with a small amount (less than 6 per cent.)

[1] Communicated by permission of the Trustees of the British Museum.
[2] O. C. Farrington, Mem. National Acad. Sci. Washington, 1915, vol. xiii, p. 227.
[3] G. D. Hinrichs, Compt. Rend. Acad. Sci. Paris, 1875, vol. lxxx, p. 1175.
[4] J. L. Smith, Amer. Journ. Sci., 1875, 3 ser., vol. x, p. 357.
[5] C. W. Gümbel and A. Schwager, Sitzungsber. München. Akad. Wiss., 1875, vol. v, p. 313.
[6] G. T. Prior, On the genetic relationship and classification of meteorites. Mineralogical Magazine, 1916, vol. xviii, p. 26.

of nickel-iron, in which the ratio of Fe to Ni is also low (less than 6). As Gümbel and Schwager's analysis was the only one to satisfy the latter condition, it was assumed to be the most accurate, and the excessive amount of the nickel-iron was attributed to its unequal distribution through the mass. Accordingly the meteorite was doubtfully referred to the Soko-Banja type (Group C 4) of chondritic stones.

In order to settle this point, however, a new analysis of this well-known meteorite seemed desirable, especially as Gümbel and Schwager's analysis was made on such a small amount of material (about 1½ gram). The British Museum Collection contains two specimens of Amana, one (48474), a large complete stone weighing 3,800 grams which was obtained by exchange from Prof. Hinrichs in June, 1875, the other (50803) a portion, now weighing 127 grams, of a stone acquired by exchange with J. Lawrence Smith in 1876. A piece of the latter specimen weighing about 12 grams was taken for analysis. The crushed material was separated by the magnetic comb into an attracted portion weighing 1·7429 grams and an unattracted portion weighing 10·2125 grams. The results of the analyses are as follows:

	Attracted.	Unattracted.	Bulk-analysis.
Fe	61·79	0·80	9·71
Ni	7·52	0·10	1·19
Co	0·61	—	0·09
Fe	0·88	4·39	3·97
S	0·51	2·52	2·28
SiO_2	5·10	44·01	39·27
Al_2O_3	—	2·40	2·10
Cr_2O_3	—	0·37	0·32
Fe_2O_3	—	0·46	0·40
FeO	2·84	13·31	12·06
MnO	—	0·09	0·08
CaO	0·63	1·92	1·78
MgO	5·66	27·47	24·88
Na_2O	—	1·03	0·92
K_2O	—	0·15	0·13
H_2O	—	0·54	0·47
P_2O_5	—	0·30	0·26
Insoluble	14·51	—	—
	100·05	99·86	99·91

The numbers given under the unattracted are the combined result of

separate analyses of the soluble and insoluble portions in hydrochloric acid, the individual numbers for which are as follows:

	Soluble.	Molecular ratios.	Insoluble.	Molecular ratios.
SiO_2	16·58	0·276	27·43	0·457
Al_2O_3	—	—	2·40	0·024
Cr_2O_3	—	—	0·37*	—
Fe_2O_3	0·46*	—	—	—
FeO	8·76	0·121	4·55	0·063
MnO	0·05	—	0·04†	—
CaO	0·42	0·007	1·50	0·027
MgO	17·46	0·436	10·01	0·250
Na_2O	—	—	1·03	0·021
K_2O	—	—	0·15	0·002
P_2O_5	0·30*		47·48	
H_2O	0·54*			
Fe	0·80			
Ni	0·10			
Fe	4·39			
S	2·52*			
	52·38			

In the following table are given for the new and the three previous analyses the percentages of nickel-iron and troilite in the meteorite, and the percentage chemical compositions of the nickel-iron and of the soluble and insoluble silicates:

	1 (Hinrichs).	2 (Lawrence Smith).	3 (Gümbel and Schwager).	4 (Prior).
Percentages of nickel-iron and troilite:				
Nickel-iron	7·5	12·54	12·32	10·99
Troilite	1·8	5·82	5·25	6·25
Composition of nickel-iron:				
Fe	88	89·07	83·38	88·37
Ni	12	10·35	16·62	10·76
Co	—	0·58	—	0·87

* These determinations were made on separate portions of the total unextracted.

† Probably under-estimated, as the separation from iron was by ammonia and not sodium acetate.

	1 (Hinrichs).	2 (Lawrence Smith).	3 (Gümbel and Schwager).	4 (Prior).
Composition of soluble silicates:				
SiO_2	37·05	36·18	38·39	38·34
Al_2O_3	—	0·72	1·01	—
FeO	28·73	27·63	28·58	20·24
MnO	—	—	0·53	0·10
CaO	1·14	—	trace	0·97
MgO	33·08	33·99	31·49	40·35
Na_2O	—	1·48	—	—
Composition of insoluble silicates:				
SiO_2	53·90	55·92	54·19	57·76
Al_2O_3	—	0·85	2·01	5·05
Cr_2O_3	—	—	1·42	0·78
FeO	19·60	27·85	25·30	9·58
MnO	—	—	trace	0·08
CaO	4·90	—	4·05	3·16
MgO	21·60	13·34	8·96	21·08
Na_2O	—	2·04	2·40	2·19
K_2O	—	—	1·67	0·32

Comparison of the results given in this table shows that the new analysis as regards the amount and chemical composition of the nickel-iron is in fairly close agreement with that of Lawrence Smith. With respect to the composition of the silicates, however, it is nearer to that of Hinrichs, for in the insoluble of analysis 1 the percentage of MgO is practically the same as in 4, and the excess of FeO is partly accounted for by its including undetermined Al_2O_3 and Cr_2O_3; while in the soluble the excess of ferrous oxide is perhaps to be attributed to included troilite and nickel-iron, the amounts of which constituents in the meteorite Hinrichs appears to have under-estimated.

The results of the new analysis show that in the nickel-iron the ratio of Fe to Ni is about 8, and that the composition of the olivine corresponds approximately to the formula $3\frac{1}{2}\,Mg_2SiO_4 . Fe_2SiO_4$ and that of the pyroxene to $4\frac{1}{2}\,MgSiO_3 . FeSiO_3 . \frac{1}{2}\,CaSiO_3$.

The meteorite thus occupies an intermediate position between the type-meteorites[1] Baroti and Cronstad of groups C 2 and C 3, as seen in the following table:

[1] G. T. Prior, loc. cit., pp. 28, 30.

	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.
Cronstad (Group C 2)	$18\frac{1}{2}$	11	$4\frac{1}{2}$
Amana	11	8	4
Baroti (Group C 3)...	9	$6\frac{1}{2}$	$3\frac{1}{2}$

Within the errors of analysis it would be difficult to decide from the ratio of MgO to FeO to which group the meteorite belongs, but the amount of nickel-iron and its composition are in favour of referring it to group 2.

The approximate mineral composition of Amana, as deduced from the new analysis, is as follows:

$Na_2O . Al_2O_3 . 6 SiO_2$ ...	7·73		
$K_2O . Al_2O_3 . 6 SiO_2$ ...	0·89	... 9·76	... Felspar.
$CaO . Al_2O_3 . 2 SiO_2$ ...	1·14		
$3 Ca_3P_2O_8 . CaO$ ...	...	... 0·22	... Apatite.
$FeO . Cr_2O_3$ ...	...	... 0·44	... Chromite.
Fe_2O_3 ...	...	... 0·40	
$CaSiO_3$ ...	2·51		
$FeSiO_3$ ...	7·06	... 30·75	... Bronzite (in which MgO : FeO = $4\frac{1}{2}$).
$MgSiO_3$ ...	21·18		
Fe_2SiO_4 ...	11·50	... 40·15	... Olivine (in which MgO : FeO = $3\frac{1}{2}$).
Mg_2SiO_4 ...	28·65		
Fe ...	9·71		
Ni ...	1·19	... 10·99	... Nickel-iron (in which Fe : Ni = 8).
Co ...	0·09		
Fe ...	3·97	... 6·25	... Troilite.
S ...	2·28		
H_2O		0·47	... Water.
		99·43	

Eagle Station.

This meteorite, of which a mass weighing about 80 lb. was found in 1880 about $\frac{3}{4}$ mile from Eagle Station, Carroll Co., Kentucky, differs in various respects from other pallasites. As pointed out in a previous paper (loc. cit., pp. 34–35), according to an analysis by J. B. Mackintosh [1], it is exceptional in chemical composition in having the nickel-iron richer in nickel and the olivine correspondingly richer in ferrous oxide. In view of the unsatisfactory character of many of the older analyses of meteorites, a new one of this pallasite seemed desirable in order to test the above result. Material for the analysis was taken from a slice (64407) in the British Museum Collection, now weighing 701 grams, which was obtained from J. Böhm of Vienna in October, 1889. The weight of material separated by the magnet used in the analysis was 2·1885 grams, that of the olivine 0·6955 gram. The results of the analyses are as follows:

	Attracted.		Olivine.		Molecular ratios.
Fe	79·74	SiO_2	39·22		0·650
Ni	13·98	FeO	18·83		0·262
Co	1·04	MgO	42·31		1·050
SiO_2	1·42		100·36		
MgO	1·74				
FeO*	0·77				
P, S, &c.	(1·31)				
	100·00				

The analyses, on the whole, confirm those of Mackintosh. In the iron the ratio of Fe to Ni is about 6, instead of over 10 as in most other pallasites; and in the olivine the ratio of MgO to FeO is about 4 instead of about 7.

This exceptional character is probably connected with other distinctive features which serve to differentiate this meteorite from other pallasites. As described by A. Brezina and E. Cohen,[2] the character of the iron distinguishes Eagle Station from all other pallasites except Bitburg (Albacher Mühle), for whereas in most pallasites the structure of the iron, as revealed by etching, presents the same orientation throughout

[1] J. B. Mackintosh, Amer. Journ. Sci., 1887, ser. 3, vol. xxxiii, p. 232.

* Calculated from the composition of the olivine.

[2] A. Brezina and E. Cohen, 'Die Structur und Zusammensetzung der Meteoreisen,' Stuttgart, 1886–1906, vol. i, Taf. xxviii.

the mass, and thus indicates a mobility of the metal through the mass during solidification, in the case of Eagle Station and Bitburg the orientation is different in different parts, as if the iron had solidified independently about different centres.

From the author's point of view of a genetic relationship of meteorites, it may be pointed out that, although this meteorite does not fit into group A 2 so well as other pallasites, the variations from the normal are consistent with the theory in as much as the greater richness in nickel of the nickel-iron is accompanied by a corresponding greater richness in ferrous oxide of the olivine. In the classification suggested in the previous paper (loc. cit., p. 42), this meteorite may perhaps be referred to the vacant space under group A 3.

The basaltic rocks of the Arctic region.

(*With Plates VI and VII.*)

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With Analyses by H. F. Harwood, M.Sc., Ph.D.

[Read November 7, 1916, January 16, 1917, and March 20, 1917.]

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1. Introduction.

THE widespread basaltic rocks of the Brito-Arctic province, like those of the Deccan and Columbia basalt-plateaux, do not seem to have received from petrologists the attention they deserve. Descriptions of particular localities and their rocks are not lacking, and the British region in particular has become classic through the investigations of Judd, Sir A. Geikie, and Dr. Harker, but hitherto no attempt has been made to survey the province as a whole, except in the most general way. Suess has traced the distribution of the plateau basalts that characterize high latitudes, and has pointed out the stratigraphical and

structural significance of the province.[1] From another point of view this has also been done by Prof. J. W. Gregory in his book 'The Nature and Origin of Fiords' (1913). A petrographical review of parts of the province is given by von Wolff,[2] and this author, considering that the basalts and their associates cannot be referred to either *Atlantic* or *Pacific* types, has proposed to distinguish them as *Arctic*.[3] The best account of the Arctic basalts, however, we owe to Sir Jethro Teall,[4] who analysed a basalt from Cape Flora, Franz Josef Land, and pointed out the wide distribution of the type, while regretting that no recent analyses of other basalts belonging to the Arctic province were then available.

Twenty years have passed, and this reproach still applies to the basalts of the Faroes, Iceland, Jan Mayen, and the east coast of Greenland. It is thus evident that chemically very little is known of the characteristics of the province, while still less is known of its extent in space and time. The object of this paper is to describe typical rocks from each of the chief localities, with chemical analyses by Dr. H. F. Harwood, so as to fill in the gaps, and prepare the foundation for a broad survey of the province with a view to determining such specific features as it may possess, and if possible to define its limits in space and time.

The rock specimens from Hare Island (West Greenland), and most of those from Iceland and the Faroes, were drawn from the petrological collections in the Geology Department of the Imperial College of Science and Technology, and for permission to investigate this material we owe our thanks to the authorities of the College. A collection of rocks that I purchased from Mr. F. H. Butler, Brompton Road, S.W., furnished specimens of basalt from Jan Mayen and Scoresby Sound (East Greenland) as well as others from Iceland and the Faroes. These specimens were obtained with the aid of a Royal Society grant for work on the radio-activity of rocks, and though the present paper is not concerned with that aspect of their study, I wish to acknowledge the assistance thus indirectly afforded. The rocks from Franz Josef Land and Spitzbergen were presented by the Director of H.M. Geological Survey (at

[1] E. Suess, 'The Face of the Earth,' 1909, vol. iv, chap. vii. A very complete bibliography and several excellent maps are given in the French edition 'La Face de la Terre,' 1911, vol. iii, pt. 2, chap. xvi.

[2] F. von Wolff, 'Der Vulkanismus,' 1914, vol. i (2), p. 427.

[3] F. von Wolff, op. cit., 1913, vol. i (1), p. 153.

[4] E. T. Newton and J. J. H. Teall, Notes on a Collection of Rocks and Fossils from Franz Josef Land. Quart. Journ. Geol. Soc., 1897, vol. liii, pp. 482–493, 1898. vol. liv, pp. 646–647.

the suggestion of Sir Jethro Teall) and by Prof. E. J. Garwood respectively, and to these gentlemen we wish to express our gratitude. Finally our thanks are due to Prof. E. Baker and Prof. W. W. Watts for placing at our disposal every facility for carrying out the analytical and petrological investigation of the rocks in the Chemical and Geological laboratories of the College.

2. Hare Island, West Greenland.

Hare Island lies at the western entrance of the Vaigat, west of the Nugsuak Peninsula and north of Disco Island. It is described in the 'Arctic Pilot' as a flat-topped basaltic island, descending abruptly to the water's edge on three sides, with a more gradual slope downwards on the north. Along the east coast there are beds of Tertiary lignite, easily accessible to whaling boats in need of fuel.[1] A small collection of rocks and minerals, comprising six different types of basalt and numerous aggregates of calcite (presumably derived from the amygdales of the basalts), was made by Mr. Thos. Reid in 1855. His specimens found their way into the Thomson collection of zeolites which was acquired a few years ago by the Geology Department of the Imperial College. The numbers attached to these and to other rocks described in this paper are those by which they are catalogued in the Imperial College collections.

Basalts free from Olivine.

No. 1554 is a fine-grained, nearly black basalt with rusty amygdales containing (in order of deposition) chlorite, chalcedony, and calcite. Under the microscope (Pl. VI, fig. 1) it is seen to be of uniform intergranular texture,[2] with here and there microporphyritic laths of labradorite (about $An_{60}Ab_{40}$). The main mass of the rock consists of laths of labradorite (about $An_{50}Ab_{50}$) between which occur granular aggregates of pale-green augite, together with a few slightly larger grains of hypersthene. Scattered profusely among the other constituents are ragged patches of haematite, and minute globules and irregular masses of magnetite and ilmenite. On account of the very fine grain it was found impossible to separate the two black ores magnetically, but in a more coarsely grained rock (1550) it was found after crushing the rock that magnetite could be picked out by a bar magnet, leaving a residuum of ore that was attracted only by an electromagnet. It is therefore likely that in No. 1554 both minerals are actually present, though the magnetite is probably a titaniferous variety.

[1] For a geological map see K. J. V. Steenstrup, Medd. om Grönland, 1883, vol. IV (end of volume).

[2] See p. 191.

There remains another mineral—the last to crystallize out—whose specific identity is not clear. It forms colourless plates generally surrounded by augite granules, and is certainly an alkali-felspar. The refractive index is less than that of Canada balsam, and, judging from the fact that it gives mottled extinction, it is probably anorthoclase. This diagnosis is supported by the analysis, for unless part of the albite is associated with orthoclase, the soda-lime felspars should be much less calcic than they really are.

The amygdales are of all sizes, from microscopically minute circular spaces filled with chlorite-stained chalcedony to masses a centimetre or more in diameter. Calcite is present only in the larger vesicles, and this fact explains the absence of carbon dioxide from the analysis.

Chemical analysis.—This rock (No. 1554) was chosen for analysis because of its freshness and comparative freedom from amygdales. A considerable quantity was crushed, the amygdaloidal portions were picked out by hand, as far as possible, and the remainder was prepared for analysis. Dr. Harwood obtained the following results:

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	48·10 ...	0·802	Quartz ...	9·87
Al_2O_3 ...	11·22 ...	0·110	Orthoclase ...	9·17
Fe_2O_3 ...	6·94 ...	0·043	Albite ...	21·48
FeO ...	8·93 ...	0·125	Anorthite ...	14·65
MgO ...	3·78 ...	0·0945		
CaO ...	8·09 ...	0·145	Diopside ...	17·69
Na_2O ...	2·56 ...	0·041	Hypersthene ...	2·65
K_2O ...	1·55 ...	0·0165		
H_2O (>110° C.)	1·26 ...	—	Magnetite ...	10·21
H_2O (at 110° C.)	0·96 ...	—	Ilmenite ...	10·79
CO_2 ...	none ...	—	Pyrite ...	0·06
TiO_2 ...	5·68 ...	0·071	Apatite ...	1·24
P_2O_5 ...	0·60 ...	0·004		
Cl ...	trace ...	—		97·81
S ...	0·04 ...	0·001	Water + BaO, less O	2·23
Cr_2O_3 ...	none ...	—		
V_2O_3 ...	0·06 ...	0·001		100·04
NiO ...	none ...	—		
MnO ...	0·23 ...	0·003		
SrO ...	trace ...	—	Class III ... Salfemane.	
BaO ...	0·03 ...	—	Order 4 ... Vaalare.	
	100·03		Rang 3 ... Vaalase.	
less O ...	0·02		Subrang 4 ... Vaalose.	
	100·01			

Specific gravity = 2·95

The analysis is remarkable for the high percentage of titanium dioxide that it reveals. This constituent is probably mainly present in the black ores, for there is nothing in the character of the augite to suggest that it is a titaniferous variety. An augite from the basalt of Ovifak (Uifak) on the adjoining island of Disco has been analysed by Nicolau,[1] who found that the percentage of titanium dioxide in the augite was only 0·72. A similar characteristic of the titaniferous basalts of the western Mediterranean has been pointed out by Washington,[2] though he remarks that one of the pale-green augites of Central Italy carried as much as 2·85 of titanium dioxide.[3]

The general features of the analysis are reserved for later discussion, though it may be of interest here to point out the chief chemical differences from the neighbouring rocks of Disco, which have been analysed by Lawrence Smith, Nauckhoff, and Nicolau.[1] Both magnesia and lime are more abundant in the iron-bearing lavas of Ovifak, while the alkalis are lower. Alumina appears to be 2 to 4 per cent. higher than in the Hare Island basalt, though this may be due to the non-determination or to a low determination of titanium dioxide. This point requires re-examination, in the light of the results placed on record in this paper.

No. 1550 is much coarser in grain than the rock described above, and contains larger and more numerous amygdales. In the latter the chief minerals are chalcedony and opal, accompanied as before by chlorite and calcite, which minerals sometimes preceded, sometimes followed, the silica.

Mineralogically the rock closely resembles No. 1554, except that no hypersthene has been detected. In texture it differs in the presence of glomeroporphyritic aggregates of clear labradorite-laths (about $An_{60}Ab_{40}$), while in places there are small cognate inclusions of brown or purple glass penetrated in ophitic fashion by laths of labradorite and carrying abundant rhomb-shaped crystals of ilmenite, which betray their nature by alteration to leucoxene. In the body of the rock the texture is intersertal, and cruciform and radiating arrangements of the felspars are common, a feature which characterizes almost all the Arctic basalts examined.

No. 1552 is an intergranular basalt in which the felspars have suffered silicification and zeolitization. Large amygdales are present, the majority

[1] T. Nicolau, Medd. om Grönland, 1901, vol. xxiv, p. 217.

[2] H. S. Washington, Quart. Journ. Geol. Soc., 1907, vol. lxiii, p. 76.

[3] H. S. Washington, The Roman comagmatic region. Carnegie Inst. Washington, 1906, Pub. no. 58, p. 134.

f which are filled by radiating masses of analcite (n between 1·472 and ·488). The smaller vesicles are occupied by clear sparkling crystals of eulandite (average n between 1·494 and 1·503, biaxial, sign +) ucceeded and corroded by chalcedony. With the latter mineral ranular aggregates of canary-yellow epidote are associated in places. Heulandite is followed by analcite, radiating needles of which can be een in many of the amygdales growing through clear patches of eulandite. Analcite in turn is followed by chalcedony, and chalcedony y calcite. Many of the felspars, especially in the neighbourhood of he amygdales, have been veined, corroded, or entirely replaced by eulandite or chalcedony or by both minerals in succession.

No. 1551 represents a still further and almost complete stage of aulo-post alteration, only the iron-ores and small windows of augite rystals remaining. Much of the rock appears originally to have been brown glass, with small amygdales of opal here and there. Of such inerals as originally existed, the felspars have been replaced by chlorite-tained chalcedony, and the bulk of the augites are represented by hloritic minerals and perhaps serpentine. Finally, the whole rock is hickly veined with bands of fibrous calcite which cut across all the arlier alteration products.

Taking the series of rocks as a whole it is clear that the order f deposition of the amygdale minerals is as follows: Heulandite, nalcite, opal, chalcedony, calcite. Chlorite may either precede the ilica minerals or follow them, and in one case it is represented by pidote. Calcite may also precede silica, but the example is exceptional.[1]

Olivine Basaltic Rocks.

No. 1555 (Plate VI, fig. 2) is a type differing very considerably from hose already mentioned. It is a fine-grained, black, vesicular rock in vhich the only amygdale mineral is stilbite, occurring as a pale-yellow ining of minute sheaves bordering the walls of some of the vesicles. The only megascopic mineral is olivine, which is present in rounded reen phenocrysts 3 or 4 mm. in diameter. In thin section it is seen hat both olivine and pale-brown augite occur as microphenocrysts, arrying inclusions of black ores, embedded in a fine-grained intersertal roundmass consisting of laths of labradorite (about $An_{65}Ab_{35}$), vaguely lefined grains of brown to purple-madder augite, and innumerable

[1] For a discussion of a similar series of amygdale minerals and their origin ee A. Holmes, The Tertiary volcanic rocks of Mozambique. Quart. Journ. Geol. oc., 1917, vol. lxxii, p. 252.

dendritic sprays of iron-ores. Except for slight marginal serpentinization of some of the smaller olivines the rock is perfectly fresh.

No. 1553 (Plate VI, fig. 3) is a dense, black rock free from vesicles, with prismatic phenocrysts of shining black augite, 4 or 5 mm. in length. Under the microscope these are seen to be beautifully idiomorphic and often in glomeroporphyritic groups. The interiors of some of the crystals are green, but the prevailing colours are brown to purple, hour-glass structure being faintly developed. The augites frequently enclose a core of olivine, which in turn includes grains of iron-ore. Olivine is also present in small, fresh, corroded crystals. Ilmenite is abundant, while felspars are poorly developed, only a few small laths of bytownite (about $An_{80}Ab_{20}$) being seen with a one-inch objective. These minerals are embedded in a dense, dark-brown groundmass thickly speckled with minute black grains and globulites. Under a quarter-inch objective a mass of incipient indeterminable felspar-laths and brown augite grains is seen merging vaguely into brown glass. The iron-ores, of which ilmenite (not attracted by a bar magnet) is the chief member, were the first minerals to commence crystallization and the last to finish.

The name and classification of this rock present difficulties. It has too little felspar to be described as olivine-basalt, too much to be styled an augitite, and two little olivine to justify the term picrite-basalt. Lacroix has recently suggested the name ankaramite [1] for mafic basaltic rocks poor in felspar and olivine; but the analysis of the type rock shows a much higher percentage of magnesia than is present in the Hare Island rock. Quite similar rocks occurring on the shores of Wood Bay, Spitzbergen, have been called trachydolerite, and nearer at hand a trachydolerite of Devonian or Carboniferous age at Nunasarnausak, Greenland, has a comparable composition (though richer in soda and poorer in potash and lime). Thus, unless a new name is to be coined, the rock may be described either as a melanocratic olivine-trachydolerite, or as a felspathic augitite.

Chemical analysis.—Unfortunately the specimen of this rock (No. 1553) was very small and only a few grams were available for analysis. Dr. Harwood was therefore unable to determine some of the rarer constituents such as chlorine and the oxides of chromium, vanadium, nickel, and barium, which were sought for in each of the other rocks analysed. The results obtained are as follows :

[1] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1916, vol. clxiii, p. 182.

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
O_2 ...	42.57 ...	0.7095	Orthoclase ...	13.90
l_2O_3 ...	14.40 ...	0.141	Albite ...	3.46
e_2O_3 ...	3.54 ...	0.022	Anorthite ...	19.74
eO ...	8.39 ...	0.117	Nepheline ...	10.62
gO ...	6.78 ...	0.1695		
aO ...	11.71 ...	0.209	Diopside ...	29.86
a_2O ...	2.70 ...	0.044	Olivine ...	4.97
$_2O$ ...	2.31 ...	0.025		
$_2O$ (>110° C.)	2.05 ...	—	Magnetite ...	5.10
$_2O$ (at 110° C.)	0.21 ...	—	Ilmenite ...	9.73
$_2$ ...	none ...	—	Apatite ...	0.30
O_2 ...	5.07 ...	0.064		
O ...	0.12 ...	0.001		97.68
...	none ...	—	Water ...	2.26
nO ...	0.10 ...	0.001		
O ...	trace ...	—		99.94
	99.98			

Class III	...	Salfemane.
Order 6	...	Portugare.
Rang 3	...	Limburgase.
Subrang 4	...	Limburgose.

Specific gravity = 3.06.

Here again the most noteworthy feature of the analysis is the high ercentage of titanium dioxide, and in this case the colour of the augites uggests that they may be titaniferous. According to the 'norm' the lagioclase should be as calcic as $An_{87}Ab_{13}$, whereas the actual mineral pproximates to $An_{80}Ab_{20}$. This may be due to constituents of the northite molecules being present in augite, or to some of the excess soda (represented in the 'norm' as nepheline) being present as albite the plagioclase. In any case most of the excess of soda and most of ae potash must be present in the glass of the groundmass. The latter annot be regarded as having the composition of a potassic analcite, for ae amount of water liberated above 110° C. is too low.

It is significant that the rock is richer in lime and magnesia and also alkalis than the basalt, No. 1554. The contrast between the two cks is very strong, one being thoroughly oversaturated with regard to lica, while the other is markedly undersaturated. In the absence of eld evidence and knowledge of the order of extrusion there is no basis r a discussion of their possible genetic relationships.

In addition to the basalts and andesites of Disco, to which references ave already been given, basalts have also been described from the north

of the Nugsuak Peninsula.[1] These comprise olivine-free and olivine-basalts (including limburgites) having porphyritic, intergranular, intersertal, radial, and vitrophyric textures in different varieties. On both Disco Island and the Nugsuak Peninsula the basalts are post-Cretaceous and are themselves cut by younger granites, as in Iceland and the Western Isles of Scotland.

3. Scoresby Sound, East Greenland.

The east coast of Greenland from Kangerdlugsuak to Scoresby Sound and Milne Land, a distance of about 250 miles, is characterized by basalt flows almost continuously. Another stretch of basalt fringes the coast for nearly 200 miles from Davy Sound to Shannon Island. Nordenskjöld has given an excellent account of the basalts of the southern belt,[2] and near Cape Dalton (south of Scoresby Sound) he discovered marine formations of Eocene age which were younger than some of the basalts and older than others. Nordenskjöld points out the remarkable uniformity of the basalts in mineral composition. No olivine was found in any of his specimens, though green alteration products sometimes occur. Red ferric oxide, as well as black ores, is very abundant. The structural varieties distinguished are: (1) dense, compact, black basalts, (2) coarsely crystalline types, (3) porphyritic varieties, (4) red basalts, scoriaceous and slaggy, and (5) amygdaloidal basalts, which are by far the most abundant.

Bøggild has described the amygdale minerals and their distribution, and he concludes that 'the basalt of the northern regions and that of Scoresby Sound seem to agree most closely as regards their minerals with that of West Greenland' (loc. cit., p. 103). The chief characteristic is the small size of the zeolites and the predominance of chabazite. In addition to many varieties of zeolites, chalcedony, quartz, and calcite are also developed. The basalts south of Scoresby Sound resemble more closely the Iceland basalts, and in them stilbite is the chief zeolite and attains a considerable size.

The specimen to be described (No. 1560, Plate VI, fig. 4) is from the south side of Scoresby Sound. It is a purple-brown basalt with small amygdales containing heulandite, chlorite, and iron-stained chalcedony, and brownish-green glass or palagonite. In thin section the rock is

[1] M. Belovsky, Zeits. Deutsch. Geol. Gesellschaft, 1905, vol. lvii, p. 68.

[2] O. Nordenskjöld, Medd. om Grönland, 1908, vol. xxviii. Map opposite p. 96. For an account of the minerals of the East Greenland basalts see O. B. Bøggild, ibid., p. 100. Nordenskjöld's map is reproduced in Suess, 'La Face de la Terre,' 1911, vol. iii (2), p. 939.

seen to consist of glomeroporphyritic bytownite (about $An_{80}Ab_{20}$) in an intersertal groundmass of small felspar-laths, grains of green augite and colourless enstatite, and very numerous small crystals of magnetite and ilmenite. Here and there are flakes of bright red haematite, and many of the augites are stained a reddish colour, apparently by the same material. The felspars of the groundmass are much more sodic than the phenocrysts, being labradorite near to andesine. All the minerals are fresh, though in many places the ultimate base of the rock seems to be chalcedony. Except in the amygdales, however, this constituent is by no means abundant.

Chemical analysis.—An analysis was made by Dr. Harwood of material (No. 1560) freed by hand as far as possible from amygdaloidal infillings. Small quantities of heulandite and of interstitial chalcedony, not visible to the naked eye, were, of course, incapable of separation. The presence of heulandite could not seriously affect the value of the analysis, for the rock as such is richer in lime and alumina than that zeolite, and the somewhat high percentage of water (above 110° C.), if wholly present in heulandite, would imply the presence of nearly 17 per cent. of the latter, which is a figure at least three times too great. The presence of high lime and alumina is, therefore, an intrinsic feature of the rock which, together with low alkalis and comparatively low iron oxides, distinguishes it from the Hare Island basalt.

	Percentages.	Molecular Proportions.
SiO_2 ...	46·84	0·781
Al_2O_3 ...	17·11	0·168
Fe_2O_3 ...	4·95	0·031
FeO ...	5·01	0·069
MgO ...	5·72	0·143
CaO ...	10·21	0·182
Na_2O ...	1·61	0·026
K_2O ...	0·69	0·007
H_2O (>110° C.)	2·53	—
H_2O (at 110° C.)	1·63	—
CO_2 ...	none	—
TiO_2 ...	3·98	0·050
P_2O_5 ...	0·19	0·001
Cl ...	trace	—
S ...	0·05	0·002
Cr_2O_3 ...	trace ?	—
V_2O_3 ...	0·01	—
NiO ...	none	—
MnO ...	0·16	0·002
SrO ...	none	—
BaO ...	trace	—
	100·69	
less O ...	0·02	
	100·67	

Mineral Composition ('Norm').		
Quartz	...	7·38
Orthoclase	...	3·89
Albite	...	13·62
Anorthite	...	37·53
Diopside	...	10·15
Enstatite	...	9·60
Magnetite	...	4·64
Haematite	...	1·76
Ilmenite	...	7·60
Pyrite	...	0·09
Apatite	...	0·30
		96·56
Water, less O	...	4·14
		100·70

Class II	...	Dosalane.
Order 5	...	Germanare.
Rang 4	...	Hessase.
Subrang 4	...	Hessose.

Specific gravity = 2·82.

4. Iceland.

The best account in English of the physical geography of Iceland is to be found in Thoroddsen's recent contribution to 'The Botany of Iceland'.[1] Sir A. Geikie has dealt with the volcanoes of the island as modern illustrations of the Tertiary activity of north-western Europe.[2] A geological map is to be found in the 'Handbuch der Regionalen Geologie',[3] where also a list of literature is given. It only remains to mention the recent work of Mr. Leonard Hawkes, whose investigations have been particularly concerned with the liparites of Iceland.[4]

Iceland is almost entirely built of volcanic rocks, of which the foundation is not seen. The following table gives the chief divisions that are recognized :—

4.	Hot Springs	Siliceous.
		Alkaline.
		Sulphur.
		Carbon dioxide.
	Active Volcanoes.	
3.	*Post-Glacial* Basalts . . .	Alluvium
2	*Quaternary* Basalts in part ice striated	Glacial gravels, conglomerates, and moraine.
1.	*Tertiary* Basalt Formation with Palagonite Formation near the top (breccias, tuffs, and conglomerates), intruded by innumerable dykes and sheets. Local flows of Liparite, and in the S.E. intrusions of Gabbro and Granophyre.	Marine *Pliocene* deposits with molluscan fauna. *Miocene* and older clay deposits of the N.W. Peninsula with lignite and impressions of plants, leaves, &c.

[1] T. Thoroddsen, Part I (2), Copenhagen and London, 1914.

[2] A. Geikie, 'The Ancient Volcanoes of Great Britain,' 1897, vol. ii, chap. xl.

[3] H. Pjeturss, Island, 1910, Bd. iv (1), p. 2.

[4] Mr. Hawkes's detailed results have not yet been published, but the following general papers are of importance :—

The building up of the North Atlantic Tertiary volcanic plateau. Geol. Mag., 1916, p. 385. Some notes on Icelandic geology. Norsk Geol. Tidsskrift, Kristiania, 1916, vol. iv (1).

The following is a list of the Iceland basalts in the Imperial College collections on which the descriptions given below are based:

Tertiary Basalts:

Non-porphyritic:

No. 387, Holmatindur, Eskifjord (Plate VI, fig. 5, Analysis, p. 192).
No. 384, Reydarfjord (south of Eskifjord).

Microporphyritic:

No. 4200, Isafjord, N.W. Peninsula.

Porphyritic, with phenocrysts of Bytownite:

No. 383, Eskifjord (Plate VI, fig. 6).
No. 1572, Isafjord, N.W. Peninsula.

Tertiary Olivine-Basalts:

Non-porphyritic:

No. 1571, Onundafjord, N.W. Peninsula.
No. 4202, ,, ,,

Porphyritic with phenocrysts of Olivine:

No. 1570, Onundafjord, N.W. Peninsula.
No. 4204, ,, ,,

Porphyritic with phenocrysts of Olivine, Augite, and Bytownite:

No. 838, Onundafjord, N.W. Peninsula.
No. 4203, Isafjord, N.W. Peninsula.

Quaternary Olivine-Basalts:

Porphyritic with phenocrysts of Olivine:

No. 837, Grundafjord, West Peninsula (Plate VII, fig. 1, Analysis, p. 196).
No. 4201, Grundafjord, West Peninsula.

In addition to the porphyritic or non-porphyritic character of the basalts, the following textures are recognized: ophitic, sub-ophitic, intergranular, and intersertal. The term *intersertal* implies a small residuum of glass between the network of felspars and the grains of augite amongst them, and there has hitherto been no satisfactory term to express the same texture in the absence of glass. The late Prof. Judd used *granulitic* for a 'holocrystalline-intersertal' texture, but this term has already a generally accepted application to granulites, and is therefore unsuitable as applied to basalts. Dr. J. W. Evans has suggested to me the term *intergranular*, and I propose to adopt it in this paper. It may be defined as a texture due to the aggregation of grains of augite, not in parallel optical continuity (as in sub-ophitic texture), between felspar-laths arranged in a network that may be diverse, or sub-radial, or sub-parallel.

Olivine-free Basalts.

No. 387 is a compact, dark-grey rock free from vesicles and porphyritic crystals. In thin section it is seen to be a fresh and characteristic type

made up of labradorite-laths in sub-ophitic relation to grains and granulated plates of enstatite-augite [1] of a pale-grey to green colour, together with comparatively large skeletal growths of ilmenite, and a small residuum of brown intersertal glass (Plate VI, fig. 5). Here and there interstitial calcite occurs between the felspars. It is evidently a late product of the consolidation of the magma, and not due to subsequent alteration. Apatite needles traversing the felspars are noticeable, and numerous minute inclusions of the same mineral (probably cross-sections of the needles) arranged roughly along the axes of the laths are frequently present.

A determination of the proportions of the minerals by volume was made by the Rosiwal micrometric method with the following results :

Labradorite*	48·0 per cent.
Enstatite-augite	38·0
Magnetite and Ilmenite ...	10·0
Glass	2·5
Calcite	1·5
	100·0

* Including apatite (from analysis nearly 1 per cent.).

Chemical analysis.—This rock (No. 387) was chosen for analysis on account of its freshness and lack of amygdales. Dr. Harwood obtained the following results :

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	48·79 ...	0·813	Quartz ...	3·60
Al_2O_3 ...	11·96 ...	0·118	Orthoclase ...	3·89
Fe_2O_3 ...	2·51 ...	0·016	Albite ...	20·44
FeO ...	12·10 ...	0·168	Anorthite ...	20·02
MgO ...	5·60 ...	0·140		
CaO ...	10·15 ...	0·181	Diopside ...	20·91
Na_2O ...	2·40 ...	0·039	Hypersthene ...	16·98
K_2O ...	0·70 ...	0·007		
H_2O (>110° C.) ...	0·40 ...	—	Magnetite ...	3·71
H_2O (at 110° C.)	0·65 ...	—	Ilmenite ...	8·06
CO_2 ...	0·41 ...	0·009	Pyrite ...	0·11

[1] W. Wahl, Die Enstatitaugite, Min. Petr. Mitt. (Tschermak), 1907, vol. xxxvi, p. 1. L. Hawkes (loc. cit., Kristiania, 1916) has also noted the presence of enstatite-augite in Icelandic basalts.

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
TiO_2 ...	4·17 ...	0·053	Apatite ...	0·93
P_2O_5 ...	0·37 ...	0·003	Calcite ...	0·90
Cl ...	trace ...	—		
S ...	0·06 ...	0·002		99·53
Cr_2O_3 ...	trace ...	—	Water, less O ...	1·03
V_2O_3 ...	0·11 ...	0·001		
NiO ...	trace ...	—		99·56
MnO ...	0·21 ...	0·003		
SrO ...	none ...	—		
BaO ...	trace ...	—	Class III ...	Salfemane.
			Order 5 ...	Gallare.
	100·59		Rang 4 ...	Auvergnase.
less O	0·02		Subrang 4 ...	Auvergnose.
	100·57		Specific gravity = 3·03.	

Hitherto there have been no complete analyses of Iceland basalts. Bunsen[1] long ago made a series of analyses which are undoubtedly good for their time, but which are now of little more than historic interest. Other old analyses by Kjerulf[2] and Schirlitz[3] are available. In none of these analyses was titanium dioxide determined, and consequently the alumina percentages are all unusually high. Otherwise Bunsen's analyses are substantially similar in their salient features to those of this paper. They indicate that the Quaternary and post-Glacial basalts do not systematically differ in bulk composition from the older basalts. The analyses of Schirlitz are remarkable for the comparatively high soda that they reveal, whereas his analyses of felspars from the same rocks indicate that the prevailing species vary from labradorite (about $An_{70}Ab_{30}$) to nearly pure anorthite.

In Dr. Harwood's analysis, the high percentage of titanium dioxide is again a noteworthy feature, and in addition the presence of 0·11 per cent. of vanadium sesquioxide calls for special mention.

No. 384 is more finely grained than No. 387, and otherwise differs from it only in the possession of microscopic amygdales of chlorite-stained opal and chalcedony.

No. 4200 is an exceedingly fine-grained (0·04 mm. average), compact rock with a well-marked conchoidal fracture. In thin section it exhibits small microphenocrysts of bytownite, in an intersertal groundmass that

[1] R. W. Bunsen, Ann. Phys. Chem. (Poggendorff), 1851, vol. lxxxiii, p. 197.
[2] T. Kjerulf, Nyt Mag. Naturvid. Kristiania, 1855, vol. viii, p. 72.
[3] P. Schirlitz, Min. Petr. Mitt. (Tschermak), 1882, vol. iv, p. 414.

appears to carry an usually high amount of black ores. Specific gravity = 3·02.

No. 383 (Plate VI, fig. 6) carries well-shaped phenocrysts of bytownite, up to 1·5 cm. in length. In thin section the bytownite is seen to be mantled with a narrow fringe of labradorite having the same refractive index as the laths of the groundmass. The latter is identical with that of No. 387, except that it is free from glass and therefore intergranular. Mineral composition, p. 197. Specific gravity = 2·96.

No. 1572 differs from No. 383 only in the possession of an intersertal groundmass and in the fact that the less calcic periphery of the phenocrysts—which are less abundant—is not so conspicuous a feature. Mineral composition, p. 197. Specific gravity = 3·05.

Olivine-Basalts.

No. 1571, like the two specimens next to be described, is a highly vesicular, almost friable rock, but notwithstanding this fact it is seen in thin section to be holocrystalline and ophitic, and, for such a rock, of coarse grain (0·4–0·5 mm. average). The felspar-laths are labradorite near to bytownite; the augite plates between them are grey-green with, in places, a slight purple tint; and the olivine, which was the earliest mineral to crystallize and is slightly larger than the other constituents, is a pale-green variety altered to reddish-brown serpentine around the borders and along cracks. Apart from this slight alteration the rock is beautifully fresh. The mineral composition is stated on p. 197, and it will be noticed that the ore minerals are notably less abundant than in the olivine-free rocks. This difference is reflected in the hand-specimens by their purple-grey or blue-grey colours, the olivine-free basalts being of a much darker hue.

No. 4202 is a similar rock, the grain being slightly coarser.

No. 1570 carries bright olive-green phenocrysts of olivine, which in thin section are seen to be colourless and free from alteration. Mineral composition, p. 197.

No. 4204 differs from the three preceding rocks in its amygdaloidal character. The material of the rock is dark and compact, and is studded with numerous white amygdales varying in size from 2 to 10 mm. In thin section still smaller ones can be detected, and throughout the only mineral infilling is stilbite. Corresponding to this difference, the pyrogenetic minerals are not so fresh as in the friable rocks. Olivine is black-bordered and veined with brown or green serpentine. Augite is

partly replaced by chlorite along cracks, and even labradorite has often a dusky appearance. Mineral composition, p. 197.

No. 838 is a pale-grey rock with large phenocrysts (up to 1 cm. in length) of fresh, transparent, green olivine. In thin section the olivine is seen to be colourless with only slight peripheral alteration, the smaller crystals having green borders. A pale pyroxene of the enstatite-augite variety occurs as small phenocrysts, and there are also a few scattered porphyritic felspars, the optical characters of which indicate its identity as bytownite, about $An_{80}Ab_{20}$. The groundmass is intergranular to sub-ophitic, and it is remarkable for its high percentage of augite, which occurs in grains or granulated plates between laths of labradorite. The mineral composition of the rock is as follows (percentage by volume):

Phenocrysts = 40 per cent.	Olivine	22
	Pyroxene	12
	Bytownite	6
Groundmass = 60 per cent.	Labradorite	21
	Augite	34
	Magnetite and Ilmenite ...	5
		100

No. 4203 contains porphyritic crystals (up to 1 × 0·5 cm.) and glomero-porphyritic aggregates of bytownite. Some of the latter are clustered about a nucleus of olivine, but both olivine and enstatite-augite are small as phenocrysts compared with the felspar. The groundmass is similar to that of No. 838, and the difference between the two rocks is clearly dependent on the proportion of the phenocrysts of bytownite and olivine.

No. 837 (Plate VII, fig. 1) is almost identical in hand-specimen and in thin section with No. 1570, although the latter belongs to the Tertiary series, while No. 837 is post-Glacial. The rock contains small, light-green, rounded phenocrysts of olivine, which in section are colourless and perfectly fresh. The rest of the rock consists of an ophitic aggregation of augite-plates and bytownite-laths (containing tiny blebs of apatite as inclusions), with small olivine nuclei among the augites, and irregular masses of ilmenite (with a very little magnetite, separable by a bar magnet) interspersed between the felspars. Part of the pyroxene is of the enstatite-augite variety, but it shades off on the borders and along terminations into augite with a faint purple tint. If this tint is due to enrichment in titanium dioxide, then the succession corresponds with

the fact that ilmenite was on the whole the last mineral to crystallize out. No glass is present.

The mineral composition of the rock (in terms of volume percentages) was determined approximately by the Rosiwal method :

Bytownite	48
Pyroxene	37
Olivine	11
Ilmenite and Magnetite... ...	4
	100

Chemical analysis.—This rock (No. 837) was analysed by Dr. Harwood with the following results :

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	47.27	... 0.788	Orthoclase ...	1.11
Al_2O_3 ...	14.44	... 0.142	Albite ...	15.72
Fe_2O_3 ...	0.97	... 0.006	Anorthite ...	30.58
FeO ...	10.15	... 0.142		
MgO ...	10.30	... 0.257	Diopside ...	21.64
CaO ...	11.73	... 0.209	Hypersthene ...	11.36
Na_2O ...	1.86	... 0.030	Olivine ...	13.05
K_2O ...	0.18	... 0.002		
H_2O (>110° C.)	0.33	... —	Magnetite ...	1.39
H_2O (at 110° C.)	0.09	... —	Ilmenite ...	4.56
CO_2 ...	none	... —	Apatite ...	0.31
TiO_2 ...	2.36	... 0.030		
P_2O_5 ...	0.12	... 0.001		99.72
Cl ...	0.01	... —	Water, &c. ...	0.44
S ...	none	... —		
Cr_2O_3 ...	0.04	... —		100.16
V_2O_3 ...	0.07	... —		
NiO ...	0.01	... —	Class III ...	Salfemane.
MnO ...	0.19	... 0.003	Order 5 ...	Gallare.
SrO ...	none	... —	Rang 4 ...	Auvergnase.
BaO ...	none	... —	Subrang 5 ...	Auvergnose.
	100.12		Specific gravity = 2.93.	

The analysis faithfully reflects the mineralogical differences between this rock and the olivine-free basalt, No. 387. Magnesia is higher, and, corresponding to the m re calcic felspar, lime and alumina are higher, while soda is lower. Ilmenite, however, is much reduced in this rock, and consequently both titanium and iron oxides are lower than in No. 387. Among the rarer constituents it is noteworthy that vanadium

esquioxide is again comparatively abundant. Evidently the Iceland basalts are richer in this constituent than the other Arctic basalts. Both nickel and chromium oxides are present in appreciable amounts, corresponding to the richness of the rock in olivine, whereas in No. 387 only traces were recorded.

No. 4201. There only remains for mention a dense, black rock which in thin section is seen to consist of fresh, colourless crystals of olivine (some idiomorphic, others corroded) in a dense, brown glass, which clears here and there and exhibits a nest of incipient felspar-laths. It may be described as an olivine-hyalo-basalt.

Mineral Composition of some Iceland Basalts.

The following approximate figures were obtained by the Rosiwal micrometric method for the mineral composition, by volume, of some of the foregoing rocks:

Olivine-free Basalts.

Minerals.	No. 387.*	No. 383.	No. 1572.	Average.
Bytownite & Labradorite	48	63	49	53.3
Pyroxene	38	29	41	36
Magnetite & Ilmenite	10	8	9	9
Glass	2.5	—	1	1.2
Specific gravity	3.03	2.96	3.05	

* Also 1.5 per cent. of calcite.

Olivine-Basalts.

Minerals.	No. 1571.	No. 1570.	No. 4204.	No. 838.	No. 837.	Average.
Bytownite & Labradorite	43	50	32	27	48	40
Pyroxene	33	31	38	45	37	37
Olivine	19	15	24	21	11	18
Magnetite & Ilmenite	5	4	6	7	4	5
Specific gravity	2.98	2.96	3.06	3.09	2.93	

The figures indicate that on an average the basalts contain a higher percentage of ores and felspars than the olivine-basalts. With the exception of the felspar content of No. 1570 this generalization is also true of the individual rocks. In each group it is interesting to notice the antipathetic relation of ores and felspars.

Relation of the Basalts to the Rhyolites.

In text-fig. 1 an attempt has been made to construct a differentiation diagram linking up Dr. Harwood's analyses with those of Prof. Bäckström.[1] On the whole the curves fit the plotted analyses very closely, but beyond

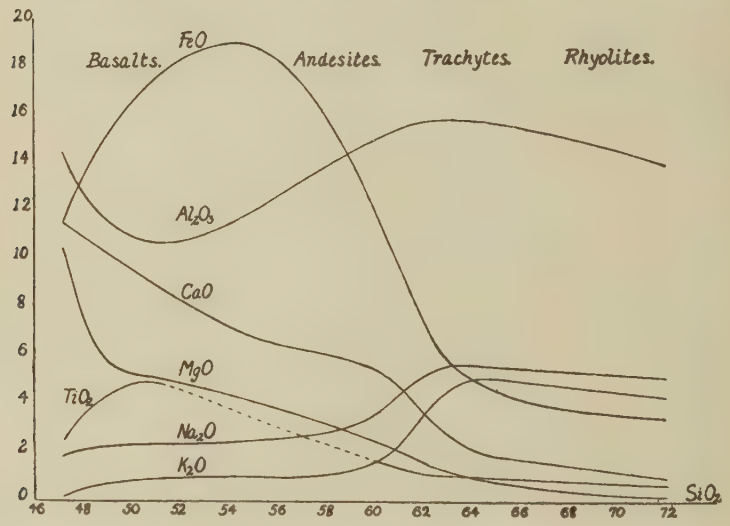


Fig. 1.—Differentiation diagram of the volcanic rocks of Iceland.

70 per cent. SiO_2 the rhyolites are evidently subject to much variation, for some are rich in orthoclase and alumina, others in soda-microcline and iron oxides. It seems clear that the post-Glacial rocks are richer in alkalis, and particularly in soda, than those of the Tertiary series. Similarly, among the basalts there can be no doubt that more analyses would reveal variations that could not be represented linearly, for the mineral composition discloses a contrast between felspathic types on the one hand and olivine-rich varieties on the other. Intermediate rocks,

[1] H. Bäckström, Beiträge zur Kenntniss der Isländischen Liparite. Geol. Fören. i Stockholm Förhandl., 1891, vol. xiii, p. 637.

however, though not known to be widely distributed, are sufficiently represented by analyses to justify the curves drawn. A striking antipathy between the oxides of alumina and iron (calculated as FeO) is displayed. Lime and the alkalis are also antipathetic, while the alkalis themselves vary sympathetically within the limits of the diagram, soda being always more abundant than potash. The crossing of the lime and alkali curves and their marked change of slope in the neighbourhood of 62 per cent. silica are features that are worthy of comparison with the corresponding behaviour in other series of rocks. In 'calc-alkali' series, such as those of the Pacific belt, the curves do not exhibit a sudden change of slope, though the crossing is generally near or at a higher silica percentage than 62. In 'alkali series', on the contrary, such as those of East Africa and the mid-Atlantic Islands, the curves change slope sharply in the neighbourhood of the crossing, and the latter takes place at a lower (often much lower) silica percentage than 62. Thus the differentiation diagram clearly brings out the fact (to which attention has been drawn by Mr. Leonard Hawkes[1] as a characteristic of the rhyolites) that the Icelandic volcanic rocks belong neither to a typical 'calc-alkali' nor to a typical 'alkali' series, but share the characters of both. Although the Tertiary igneous suite of the British Isles has been complicated by much subsidiary differentiation, the main outlines are clearly similar to those of Iceland, and lead to a similar deduction. The Icelandic basalts are typical of those described in this paper, and thus it would seem that the conception embodied in von Wolff's proposal of an *Arctic* suite, as opposed to both *Atlantic* and *Pacific* suites, is justified. I say the conception is justified rather than the term, because geographical terms have not been successful in petrological generalizations, the reason being partly because of the existence of intermediate and composite suites such as this now being discussed, and the 'spilitic suite', and partly because 'Atlantic' and 'Pacific' series may be closely associated both in time and place.

5. The Faroe Islands.

The field relations of basaltic flows, tuff partings, and intrusions of the Faroes have been thoroughly described by the late James Geikie.[2] In three of the islands there occur partings of coal and carbonaceous sediments of Miocene age between the basaltic rocks, the age of which is thus approximately fixed. The basalts are similar to those of Iceland,

[1] L. Hawkes, Norsk Geol. Tidsskrift, Kristiania, 1916, vol. iv (1), p. 42.

[2] J. Geikie, On the geology of the Faröe Islands. Trans. Roy. Soc. Edinburgh, 1880, vol. xxx, p. 217 (Geological map, Pl. XVI).

comprising olivine and olivine-free varieties and presenting a similar range of textures. A petrological description of a basalt from Kolter, with an incomplete analysis, has been given by Osann.[1]

The following is a list of the basalts described below :

Nos. 385 and 1412, Waags-fjord, Suderöe.

Nos. 386, 4007, 4008, Thorshavn, Stromöe.

No. 1413, Osteröe.

Of these, No. 385 is older than the Miocene coal partings, while the rest are of later date. Only No. 1413 carries olivine.

No. 385 is a dark, compact, grey-green rock. Under the microscope (Plate VII, fig. 3) it reveals microphenocrysts of labradorite in glomero-porphyritic aggregation, in a sub-ophitic groundmass consisting of labradorite-laths (having the same average refractive index as the small phenocrysts) and granular plates of pale-green, slightly pleochroic enstatite-augite. Well-shaped and skeletal crystals of ilmenite are very abundant. Minute inclusions of a similar opaque mineral occur in the felspars, but the great bulk of ilmenite was the last of the essential minerals to crystallize out. Rounded grains of pyroxene (probably hypersthene) and tiny blebs of apatite are also included by the felspars. There is a small amount of residual glass, sometimes brown and carrying globulites, sometimes green and showing incipient crystallization.

Measured by the Rosiwal method, the mineral composition of the rock by volume is as follows, that of No. 1412 being also given for comparison :

	No. 385	No. 1412
Labradorite	45*	42
Pyroxene	39	43
Magnetite and Ilmenite	12	13
Glass	4	2
Specific gravity	2·89	2·92

* Including small quantities of the other constituents as inclusions.

No. 1412 is, as the figures show, almost identical with No. 385. Microscopically it differs in having a finer grain and in the complete absence of microphenocrysts.

[1] A. Osann, Neues Jahrb. Min., 1884, vol. i, p. 45.

These rocks are less felspathic than the Icelandic olivine-free basalts, d they carry greater quantities of pyroxene and ilmenite. Nevertheless e analysed rocks, No. 385 (Faroe) and No. 387 (Iceland), are very osely similar, and the similarity is brought out even more closely by e analyses.

Chemical analyses of No. 385.—This rock was analysed by Dr. rwood with the following results :

		Percentages.		Molecular Proportions.	Mineral Composition ('Norm').		
$)_2$	...	49·70	...	0·828	Quartz	...	8·06
O_3	...	10·98	...	0·108			
O_3	...	3·02	...	0·019	Orthoclase	...	3·72
)	...	11·19	...	0·156			
O	...	5·34	...	0·1335	Albite	...	18·34
)	...	9·71	...	0·173	Anorthite	...	18·35
$_2O$	...	2·22	...	0·035			
)	...	0·63	...	0·007	Diopside	...	22·22
) (>110° C.)...		0·96	...	—	Hypersthene	...	12·83
) (at 110° C.)		0·92	...	—			
2	...	none	...	—	Magnetite	...	4·41
$)_2$	...	4·83	...	0·060	Ilmenite	...	9·12
$)_5$	...	0·35	...	0·003	Pyrite	...	0·24
	...	0·02	...	0·0006	Apatite	...	1·01
	...	0·05	...	0·002			
							98·30
O_3	...	trace	...	—			
$)_3$	...	0·03	...	—	Water	...	1·88
)	...	none	...	—			
O	...	0·22	...	0·003			100·18
	...	none	...	—	less O	...	0·02
)	...	0·01	...	—			
							100·16
		100·18					
O for S	...	0·02			Class III	...	Salfemane.
					Order 4	...	Vaalare.
		100·16			Rang 3	...	Vaalase.
					Subrang 4	...	Vaalose.

Specific gravity = 2·89.

Corresponding to the greater amount of ilmenite seen in thin section, analysis reveals a higher percentage of titanium dioxide than in the esponding Iceland rock. Otherwise the only notable difference is the h lower percentage of vanadium sesquioxide. The analysis closely the curves on the Icelandic differentiation diagram, text-fig. 1. The aining rocks to be described can also be matched by Icelandic types,

the higher percentage of felspar bringing the two series into detailed parallelism.

No. 386 (Plate VII, fig. 4) is a porphyritic basalt without vesicles, and Nos. 4007–8 are similar rocks, except that they contain vesicles here and there with occasional crystals of stilbite. All these have a groundmass that appears to be identical with that of No. 385, except in the size of grain. The only important difference is, therefore, the possession of porphyritic felspars up to 1 cm. in length in place of the small glomeroporphyritic aggregates of the analysed rock. The large felspars are a more calcic variety of labradorite than the laths, and, as in the Iceland rocks, there is often a less calcic fringe of the same composition as the laths. The two varieties are approximately $An_{70}Ab_{30}$ and $An_{50}Ab_{50}$.

No. 1413 is a light-grey, vesicular rock with porphyritic labradorite and small microphenocrysts of corroded olivine, now entirely altered to serpentine. As in the Icelandic olivine-basalts, augite is more abundant than in those free from olivine, but the special characteristic of the Faroe rocks, richness in ilmenite, is still maintained. The groundmass is intergranular with intersertal patches where a little pale-green glass still remains. Specific gravity = 2·86.

6. Jan Mayen.

Jan Mayen is an inhospitable, fog-ridden island so extremely difficult of access that very little as yet is known about it.[1] It consists of the most northerly active volcano in the world, Beerenberg, rising steeply up from great depths to a height of 8,000 feet above the sea, with a long lava ridge stretching away to the south-west, the total length being about thirty miles. The island was roughly surveyed by the Austrian 'Pola Expedition' of 1882–3, and some rocks were collected, which were described by Scharizer.[2] These consisted of a porphyritic olivine-basalt from the south of the island, another from Mt. Danielsen, and another from Mary Muss Bay, together with an aegirine-trachyte from 'Eierinsel'. Analyses are given of the four rocks, but they are unreliable and incomplete. They are interesting chiefly in showing that the rocks are much richer in alkalis than any other of the Arctic volcanic rocks yet mentioned.

[1] See W. S. C. Russell, Bull. Amer. Geogr. Soc., 1911, vol. xliii, p. 881.

[2] R. Scharizer, Jahrb. geol. Reichsanst. Wien, 1884, vol. xxxiv, p. 707. See also P. Reusch, 'Det Norske Nordhavs Expedition, 1876–1878,' 1882, p. 5 and fig. 4.

a characteristic that is verified by Dr. Harwood's analysis of the Mary Muss Bay rock (olivine-trachyandesite).

This is a dark-grey, compact, and basaltic-looking rock (No. 4208), with clear glassy idiomorphs of andesine (5 × 2 mm.; mean n slightly above 1·544; nearly straight extinction on both cleavages; specific gravity = 2·66). The composition is uniform throughout, there being no indications of zoning, but while the formula representing the composition may be partially stated as An_{30}, the analysis shows that the remainder cannot be Ab_{70}, for nearly half the normative alkali felspar is orthoclase. Possibly the felspar contains occult molecules of both orthoclase and carnegieite.

Under the microscope (Plate VII, fig. 2) the main body of the rock is seen to consist of small microphenocrysts of fresh colourless olivine, generally rounded and in places penetrated by the groundmass, together with a few faintly zoned pale-brown to purple augites in a very fine groundmass. The latter consists of felspar-laths (of average $n = 1{\cdot}544$) finely striated between crossed nicols, grains of green to brown augite, irregular specks of titaniferous magnetite, and a confused residuum containing small quantities of calcite, nepheline, and probably orthoclase. Careful search was made for orthoclase and nepheline in view of the analysis, but very little of either could be detected. Nearly isotropic patches with almost the same refractive index as Canada balsam were referred to nepheline and others with higher birefringence and lower refractive index to orthoclase. Apatite occurs as blebs in olivine, and each of these minerals is included by the larger augites. The rock betrays not the slightest trace of alteration either by weathering or hydrothermal action, and the calcite of the groundmass thus may be interpreted as a final low temperature product of the construction of the rock, rather than the first sign of its destruction.

The classification of this rock presents some difficulty, as it conforms to the demands of neither basalt nor andesite.[1] Iddings has suggested the name hawaiite for 'andesite-basalts' such as are developed in the Hawaiian Islands,[2] and the Jan Mayen rock resembles many of these sufficiently to fall under the same name. However, the relatively high potash revealed chemically indicates that the rock may be reasonably described as an *olivine-trachyandesite*. Rosenbusch would undoubtedly have called it a trachydolerite, but it seems advisable to retain this term for rocks with plagioclase at least as calcic as $An_{50}Ab_{50}$.

[1] A. Holmes, Geol. Mag., 1917, p. 121.

[2] J. P. Iddings, 'Igneous Rocks,' 1913, vol. ii, p. 198.

Chemical analysis.—The rock (No. 4208) was analysed by Dr. Harwoo with the following results:

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	45·08 ...	0·751	Orthoclase ...	10·5
Al_2O_3 ...	14·15 ...	0·139		
Fe_2O_3 ...	2·28 ...	0·014	Albite ...	23·7
FeO ...	8·59 ...	0·120	Anorthite ...	15·2
MgO ...	7·01 ...	0·178		
CaO ...	10·20 ...	0·182	Nepheline ...	5·6
Na_2O ...	3·99 ...	0·065		
K_2O ...	1·79 ...	0·019	Diopside ...	13·7
H_2O (>110° C.)	0·75 ...	—	Olivine ...	14·8
H_2O (at 110° C.)	0·15 ...	—		
CO_2 ...	2·42 ...	0·055	Magnetite ...	3·2
TiO_2 ...	2·93 ...	0·037	Ilmenite ...	5·6
P_2O_5 ...	0·62 ...	0·004	Pyrite ...	0·1
Cl ...	trace ...	—	Apatite ...	1·3
S ...	0·09 ...	0·003	Calcite ...	5·8
Cr_2O_3 ...	0·01 ...	—		
V_2O_3 ...	0·05 ...	—		99·8
NiO ...	none ...	—	Water ...	0·9
MnO ...	0·22 ...	0·003		
SrO ...	0·05 ...	0·001		100·
BaO ...	0·06 ...		less O ...	0·
	100·44			100·
less O for S ...	0·03			
	100·41			

Class III	...	Salfemane.
Order 5	...	Gallare.
Rang 3	...	Camptonase.
Subrang 4	...	Camptonose.

Specific gravity = 3·01.

The analysis differs from those of the normal Arctic basalts most co spicuously in the high alkalis, and for the first time as we pass fro west to east the percentage of titanium dioxide falls below the sum the alkalis. In view of the fact that Scharizer describes chrome-diopsi from his basalts, special care was taken to determine Cr_2O_3 in this roc but only 0·01 per cent. was found. The olivine-basalt of Iceland—a richer in magnesia—contains four times as much. The oxides of strontiu and barium are noticeably abundant, a feature to be correlated with t presence in the rock of relatively high lime and alkalis together.

The analysis corresponds very closely with some of those of t

titaniferous basalts of the western Mediterranean,[1] though mineralogically it differs somewhat, as the rocks described by Washington nearly all have labradorite as their prevailing felspar. The general relation of the Arctic and western Mediterranean titaniferous provinces will be discussed later. The resemblance to the 'andesine-basalts' of Hawaii[2] has already been mentioned, and, here too, many of the rocks carry a high percentage of titanium dioxide. Moreover, in all these regions, there is a further parallelism in the association of alkali-trachytes with the far more abundant basaltic types. The closest analogues, however, are not so far to seek, for the 'trachydolerites' of the extinct volcano of Mt. Sverre, Wood Bay, Spitzbergen, are very similar rocks, their most calcic plagioclase being $An_{40}Ab_{60}$, and therefore well within the range of olivine-trachyandesite as defined on the felspar basis. Analyses of the Sverre rocks are quoted on p. 206.

7. Spitzbergen.

There is a more extensive literature on the petrology of the basaltic rocks of Spitzbergen, and one, moreover, elaborated by several analyses, than can be found for any other of the islands dealt with in this paper. Geographically the volcanic and associated intrusive rocks of Spitzbergen may be divided into three groups: a southern one distributed around the shores of Storfjord in the south-east and described by Backlund;[3] a central group along Icefjord and the Sassendal;[4] and a northern series around the shores of Wood Bay.[5] To the east of Spitzbergen, the basaltic rocks of King Charles (Kung Karls) Land form a fourth group.[6]

[1] H. S. Washington, Quart. Journ. Geol. Soc., 1907, vol. lxiii, p. 74 (General); Amer. Journ. Sci., 1907, vol. xxiv, p. 217 (Catalonia); Journ. Geol., 1908, vol. xvi, p. 1 (Linosa); Amer. Journ. Sci., 1909, vol. xxvii, p. 131 (Submarine Eruptions); Journ. Geol., 1914, vol. xxii, p. 16 (Pantelleria).

[2] W. Cross, U.S. Geol. Survey, Prof. Paper No. 88, 1915.

[3] H. Backlund, Les Diabases du Spitzberg oriental. Missions scientifiques pour la mesure d'un arc de méridien au Spitzberg. 1899-1901, Mission Russe, 1907, II, ix, B, 1.

[4] A. E. Nordenskiöld, Geol. För. i Stockholm Förh., 1874 5, vol. ii, p. 259. Sir Martin Conway, 'The first crossing of Spitzbergen,' London, 1897.

[5] A. Hoel and O. Holtedahl, Les nappes de lave, les volcans, &c., de la Baie Wood. Skrifter Vidensk.-Selsk. Christiania, Math.-Naturv. Kl., 1911, No. 8 (Geol. map opp. p. 18).

V. M. Goldschmidt, Petrographische Untersuchungen, ibid., 1911, No. 9.

[6] A. Hamberg, Über die Basalte des König Karls Landes. Geol. För. i Stockholm Förh., 1899, vol. xxi, p. 509.

A. G. Nathorst, Einiges über die Basalte des Arktischen Gebietes. Ibid., 1892, vol. xiv, p. 69.

See also ibid., 1901, vol. xxiii, p. 341, and Bull. Geol. Inst. Univ. Upsala, 1910, vol. x, p. 316.

Backlund states that the diabases of Storfjord occur as sills of remarkable regularity cutting schists of the Permo-carboniferous and Jurassic strata, but never beds of younger age. Structurally both intergranular and intersertal types occur, porphyritic plagioclase being more evident in the latter. The porphyritic crystals are zoned, the cores being about $An_{70}Ab_{30}$, while the envelopes range from $An_{40}Ab_{60}$ to $An_{30}Ab_{70}$. The order of crystallization is given as follows: olivine (when present), magnesian-diopside, cores of plagioclase, augite, envelopes of plagioclase, titaniferous magnetite. Chemically, the rocks differ in three chief ways from those of other analysed Arctic rocks. Alumina is high (19–21 per cent.) and calcium is low. This combination is significant, for with it, and also with the presence of olivine, goes low titanium dioxide (not exceeding 1·2 per cent. in five analyses). The difference may be correlated with the richness of the rocks analysed in porphyritic plagioclase, for the only rock of a similar character analysed by Dr. Harwood contains more than 17 per cent. of alumina (Scoresby Sound, see p. 189).

Around Wood Bay the igneous history is longer and more interesting. It began in the Jurassic or Cretaceous with lava flows and sheets of basalt containing purple-brown augite and generally a little olivine. The composition of two examples is given below (A and B) with analyses of later rocks from the same neighbourhood.

	A	B	C	D	E	F
SiO_2 ...	49·75	50·19	44·49	45·12	45·88	44·66
Al_2O_3 ...	12·96	12·37	10·93	13·63	13·52	12·97
Fe_2O_3 ...	3·45	2·04	2·78	3·20	2·48	3·84
FeO ...	8·80	9·60	8·24	7·84	7·74	7·55
MgO ...	8·92	8·99	11·22	9·37	9·09	9·35
CaO ...	7·69	7·93	8·58	8·93	8·55	8·82
Na_2O ...	3·15	3·20	3·16	4·68	4·53	4·24
K_2O ...	0·97	0·87	2·25	2·05	2·52	2·78
H_2O (>110° C.)	0·44	0·12	0·76	0·43	0·74	0·69
H_2O (at 110° C.)	0·25	0·08	0·55	0·36	0·17	0·48
CO_2 ...	trace	trace	0·86	trace	trace	none
TiO_2 ...	1·38	1·47	2·60	2·69	2·87	2·76
ZrO_2* ...	1·18	2·02	2·10	—	—	—
P_2O_5 ...	0·62	0·63	0·92	0·93	1·19	1·10
Cr_2O_3 ...	0·02	0·03	0·02	0·01	0·01	0·01
NiO ...	0·02	0·11	0·07	0·48	0·14	0·26
MnO ...	0·16	0·18	0·17	0·23	0·22	0·21
	99·96	99·83	99·71	99·95	99·64	99·71

A, B. Cape Augusta Victoria, Spitzbergen.
C, Volcanic neck, Mt. Halvdan.
D, E, F. Mt. Sverre.
} Dittrich, Analyst.

* Unfortunately this improbable constituent is described as the 'différence entre la détermination colorimétrique et gravimétrique de TiO_2'. Goldschmid accepts the colorimetric estimation and adds the difference to Al_2O_3, which probably, it is more likely to be than anything else.

On the west of Wood Bay there occurs a volcanic neck of olivine-trachydolerite of Tertiary or early Quaternary age (analysis C). The later Quaternary volcano of Mt. Sverre is built of rocks which have been termed olivine-trachydolerite and nepheline-basanite (analyses D–F). In most specimens the nepheline is accessory, and the rocks recall the olivine-trachyandesite of Jan Mayen. The felspar being andesine, that term should replace trachydolerite. With increasing nepheline the rocks pass into basanite, in which a range of felspar from andesine to bytownite is sanctioned by custom.

The three series of rocks demonstrate that their parent magmas became steadily richer in alkalis, and particularly in potash, as Recent time was approached. The last phase of volcanic activity is represented by thermal springs, probably the most northerly examples in the world.

The basalts of King Charles Land (Kap Weissenfels) resemble those of Hare Island, but magnetite largely takes the place of ilmenite, and the rocks have low titanium dioxide and high iron oxides.

Basalt (*Dolerite*) *from the Sassendal, Central Spitzbergen.*

This rock, like the diabase of Storfjord, occurs as an intrusive sheet in the Jurassic beds of the Sassendal. It was sent to us by Prof. E. J. Garwood, from his collection made on the Conway Expedition to central Spitzbergen.

In the hand-specimen it is a grey, granular rock of 0·5 mm. grain. Specific gravity = 2·86. In thin section (Plate VII, fig. 5) it is seen to be ophitic in texture and by no means free from interstitial glass. The felspar-laths are of labradorite, approximately $An_{55}Ab_{45}$, arranged in radial groupings and often penetrating pyroxene, which is a nearly colourless variety belonging to the enstatite-augite series, and having a low optic axial angle. The pyroxene is generally in irregular plates, but a few idiomorphic crystals may be seen. It is clear that olivine originally crystallized from the magma, but now only a few rare serpentinized and deeply corroded relics remain. Titaniferous magnetite and apatite occur as accessories, the former being definitely of later crystallization than most of the felspar, and the latter in part of earlier crystallization, since it is sometimes present in tiny prisms as inclusions. There are also later apatites of needle-like and acicular habit clinging to the edges of the felspar-laths and associated particularly with the interstitial materials of the rock. These are of three kinds: in order of consolidation, brown glass, pale-grey chalcedony, sometimes chlorite-stained, and calcite. The calcite occurs partly as interstitial matter

associated with chalcedony, and in one slide a small amygdale was seen lined with quartz and otherwise filled with calcite.

The mineral composition by volume is approximately as follows :

Labradorite	40
Enstatite-augite	28
Serpentine	1·5
Titaniferous Magnetite	8
Apatite	n. d.
Glass	16
Quartz, Chalcedony, and Chlorite ...	4·5
Calcite	2
	100

Chemical analysis.—The rock was analysed by Dr. Harwood with the following results :

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	50·17	0·836	Quartz ...	10·74
Al_2O_3 ...	13·66	0·135	Orthoclase ...	6·12
Fe_2O_3 ...	5·40	0·034		
FeO ...	6·59	0·094	Albite ...	17·29
MgO ...	5·31	0·133	Anorthite ...	25·30
CaO ...	9·26	0·166		
Na_2O ...	2·06	0·033	Diopside ...	12·96
K_2O ...	1·00	0·011	Hypersthene ...	9·68
H_2O (>110° C.)	1·28	—		
H_2O (at 110° C.)	1·02	—	Magnetite ...	7·89
CO_2 ...	0·44	0·010	Ilmenite ...	5·62
TiO_2 ...	2·93	0·037	Pyrite ...	0·48
P_2O_5 ...	0·28	0·002	Apatite ...	0·66
Cl ...	trace	—	Calcite ...	1·00
S ...	0·24	0·008		97·74
Cr_2O_3 ...	none	—		
V_2O_3 ...	0·05	—	Water ...	2·30
NiO ...	none	—		100·04
MnO ...	0·15	0·002		
SrO ...	0·05	0·0006	less O	0·09
BaO ...	0·03			99·95
	100·02			
less O for S ...	0·09			
	99·93			

Specific gravity = 2·86.

Class III ...	Salfemane.
Order 5 ...	Gallare.
Rang 4 ...	Auvergnase.
Subrang 4 ...	Auvergnose.

The analysis shows that the rock has the general character of the

saturated non-porphyritic type of Arctic basalt, except that titanium dioxide is—in common with other Spitzbergen rocks—considerably reduced.[1] Remembering this minor difference, which is possibly geographical, it is interesting to notice that Spitzbergen possesses all the chief mineralogical and chemical types of the Arctic basalts. The saturated types differ mainly according to the absence or presence of porphyritic felspars, those with phenocrysts always being much richer in alumina. The undersaturated types may be similarly divided, while the normal olivine-basalts must be distinguished from the more alkaline rocks that constitute the series trachyandesite, trachydolerite, nepheline-basanite.

8. Franz Josef Land.

A detailed account of the basaltic rocks (whether they are lava flows or intrusions is not yet known) collected by the Jackson-Harmsworth Expedition of 1894–6 has already been published by Sir Jethro Teall[2] and at his kind suggestion a specimen from Hooker Island (311, Old Depot) was sent to us by the Director of the Geological Survey.

The specimen analysed by Teall[3] was an undersaturated basalt (with normative olivine) from Cape Flora, Northbrook Island, whereas that analysed by Harwood, from Hooker Island, is a saturated basalt (with normative quartz). With the exception of minor chemical differences the two rocks are remarkably similar, and only a brief description of the Hooker Island specimen need be given (Plate VII, fig. 6).

The rock is a massive coarse-grained basalt (2 mm. grain with a sprinkling of slightly larger glomeroporphyritic crystals) which in thin section is seen to be ophitic, and to carry a residuum of brown interstitial glass. The larger felspars are slightly zoned, the composition ranging from approximately $An_{70}Ab_{30}$ down to $An_{50}Ab_{50}$. The pyroxene belongs partly to the enstatite-augite series, having a hypersthene-like aspect in all but pleochroism, which is feeble. This merges vaguely into a brown-green type of later consolidation. Olivine and its alteration products were sought for in two sections, but none was found. About 7 per cent. of titaniferous magnetite occurs, chiefly of late crystallization.

[1] A very similar rock occurs on Gans Island, Spitzbergen. As far as Lindström's (1867) analysis goes (for the alkalis were not determined) it is closely like the Sassendal basalt and 2·97 per cent. of TiO_2 is recorded. See R. von Drasche, Tschermak's Min. Mitth., 1874, pp. 263–265. Most of the analyses, however, show a lower content of titanium dioxide.

[2] J. J. H. Teall, Quart. Journ. Geol. Soc., 1897, vol. liii, p. 482 (Locality map, p. 478).

[3] J. J. H. Teall, ibid., 1898, vol. liv, p. 646.

The interstitial matter is of the kinds described by Teall, brown glass locally passing into grey, and small patches of deep brown palagonite exhibiting aggregate polarization between crossed nicols.

The mineral composition by volume is approximately as follows:

Labradorite	45
Pyroxene	34
Titaniferous Magnetite	7
Glass and Palagonite	14
	100

It may be noticed here, and also in the Sassendal basalt, that the normative magnetite and ilmenite considerably exceeds the amount of titaniferous magnetite found by measurement. The difference is probably to be found in the glass or palagonite of the rocks, and it is interesting to note that Teall's analysis of palagonite [1] reveals a marked concentration of iron oxides (26 per cent. in the latter).

Chemical analysis.—Dr. Harwood analysed the Hooker Island basalt with the following results:

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	48·89 ...	0·813	Quartz ...	4·10
Al_2O_3 ...	14·30 ...	0·140	Orthoclase ...	2·78
Fe_2O_3 ...	4·71 ...	0·029		
FeO ...	7·60 ...	0·110	Albite ...	19·39
MgO ...	6·11 ...	0·152	Anorthite ...	27·24
CaO ...	11·04 ...	0·197		
Na_2O ...	2·31 ...	0·037	Diopside ...	20·82
K_2O ...	0·47 ...	0·005	Hypersthene ...	12·08
H_2O (>110° C.)	0·72 ...	—		
H_2O (at 110° C.)	1·57 ...	—	Magnetite ...	6·75
CO_2 ...	trace ...	—	Ilmenite ...	4·41
TiO_2 ...	2·29 ...	0·029	Apatite ...	0·64
P_2O_5 ...	0·24 ...	0·002		
Cl ...	trace ...	—		98·26
S ...	trace ...	—	Water ...	2·29
Cr_2O_3 ...	0·02 ...	—		
V_2O_3 ...	0·06 ...	—		100·49
NiO ...	trace ...	—	Class III ...	Salfemane.
MnO ...	0·18 ...	0·003	Order 5 ...	Gallare.
SrO ...	none ...	—	Rang 4 ...	Auvergnase.
BaO ...	trace ...	—	Subrang 5 ...	Auvergnose.
	100·51		Specific gravity = 2·91.	

[1] J. J. H. Teall, loc. cit., 1897, p. 485.

Sir Jethro Teall's analysis of the Cape Flora specimen is given below for comparison:

	Percentages.	Molecular Proportions.	Mineral Composition ('Norm').	
SiO_2 ...	47·28	0·788	Orthoclase ...	1·67
Al_2O_3 ...	13·24	0·130	Albite ...	22·01
Fe_2O_3 ...	4·44	0·027	Anorthite ...	23·63
FeO ...	10·50	0·146		
MgO ...	5·94	0·149	Diopside ...	25·57
CaO ...	11·04	0·197	Hypersthene ...	12·63
Na_2O ...	2·62	0·042	Olivine ...	2·68
K_2O ...	0·31	0·003		
Loss on Ignition	2·00	—	Magnetite ...	6·26
TiO_2 ...	1·48	0·018	Ilmenite ...	2·74
MnO ...	0·40	0·006		
	99·25		Loss on Ignition ...	2·00
				99·19

III, 5, 4, 5, Auvergnose.

The chief differences between the analyses are that the Hooker Island specimen is richer in silica, alumina, and titanium dioxide than that from Cape Flora, while the latter is richer in ferrous oxide. The characteristic antipathetic relation between alumina and iron oxides is thus exemplified, while the behaviour of titanium dioxide illustrates a rule that applies to every individual locality described: that the saturated type of basalt is richer in that constituent than the undersaturated type.

9. Classification of the Arctic Basaltic Rocks.

In the preceding descriptions various classifications, textural and mineralogical, have been made use of, but that summarized to fit the Spitzbergen rocks seems to be the most suitable for a general review. The first division into saturated (or oversaturated) and undersaturated types is probably most fundamental, separating rocks with actual or normative quartz from those containing olivine. The latter may be further divided according to the presence or absence of actual or normative nepheline. Each of the three groups may be indefinitely subdivided according to texture and mineral composition, but the outstanding feature of classificatory importance is the presence or absence of macroporphyritic plagioclase. Six series of rocks are thus formed, within each of which the rocks have a marked chemical and mineralogical resemblance.

Classification and Distribution of the Arctic Basaltic Rocks.

	Saturated.	Undersaturated.	
Characteristic Minerals of 'Norm' or 'Mode'.	Quartz.	Olivine.	Olivine and Nepheline.
Without Phenocrysts of Plagioclase.	*Basalts.* All Localities, except Jan Mayen.	*Olivine-Basalts.* All Localities.	*Trachydolerite.* Hare Is.
With Phenocrysts of Plagioclase.	All Localities, except Jan Mayen.	All Localities, but not abundantly developed.	*Trachyandesite.* Spitzbergen, Jan Mayen. *Trachydolerite.* Spitzbergen. *Nepheline-basanite.* Spitzbergen.
Amygdale Minerals.	Forms of Silica. Zeolites, Calcite.	Forms of Silica only present in hydrothermally altered rocks. Zeolites and Calcite.	
Rock Associations.	*Andesite* (Disco, Iceland, King Charles Land). *Rhyolite* (Iceland). *Granite* (Nugsuak Peninsula, Disco, and Iceland).		*Alkali-Trachyte* (Jan Mayen).

In the American quantitative classification the distinctions recognized above are clearly brought out, except that in Order 5 (which means that the ratio of normative quartz or felspathoid to total felspar is less than 1 : 7) both saturated and undersaturated rocks may occur, the presence or absence of small quantities of quartz, felspathoid, or olivine being ignored as without significance.[1] The magmatic symbols for the rocks analysed by Dr. Harwood and others are as follows:

III, 4, 3, 4. Basalt: Hare Island, Greenland.
Basalt: Suderöe, Faroe Islands.
III, 5, 3, 4. Olivine-basalt: Wood Bay, Spitzbergen.
Olivine-trachyandesite: Jan Mayen.

[1] For a development of this criticism see A. Holmes, A mineralogical classification of igneous rocks. Geol. Mag., 1917, pp. 115–130.

III, 6, 3, 4.	Olivine-trachydolerite: Hare Island, Greenland.
	Nepheline-basanite: Wood Bay, Spitzbergen.
III, 4, 4, 4.	Diabase: Kuzkin Island, Siberia.[1]
III, 5, 4, 4.	Diabase: Kuzkin Island, Siberia.[1]
	Diabase: Sassendal, Spitzbergen.
	Basalt: Disco Island, Greenland.
II, 5, 4, 4.	Porphyritic-basalt: Scoresby Sound, Greenland.
	Porphyritic-diabase: Storfjord, Spitzbergen.
III, 5, 4, 5.	Basalt: Disco Island, Greenland.
	Basalt: Iceland.
	Olivine-basalt: Iceland.
	Basalt: Cape Flora, Franz Josef Land.
	Basalt: Hooker Island, Franz Josef Land.

Throughout, the rocks have approximately equal amounts of 'salic' and 'femic' minerals (III) except in the markedly porphyritic rocks of Scoresby Sound and Spitzbergen, where 'salic' dominates (II). The rocks range from oversaturated (Orders 4, 5) to undersaturated (Orders 5, 6) types; alkalis are always subsidiary to lime (Rangs 3 and 4), and of the alkalis soda is always dominant or predominant (Subrangs 4 and 5).

10. Review of the Chemical Characters.

In the table given below the chief constituents of the nine analyses made by Dr. Harwood are averaged, and similar averages for the basalts of the British area,[2] of Washington's western Mediterranean province[3] (Linosa, Pantelleria, Sardinia, and Catalonia), and of those of the Hawaiian Islands[4] are listed for comparison, together with the average of all basalts computed by Osann and Daly.[5]

[1] H. Backlund, Kristalline Gesteine von der Nordküste Sibiriens. I. Die Diabase der Kusjkin-Insel. Mém. Acad. Sci. St. Pétersbourg, 1910, vol. xxi, No. 6.

[2] A. Harker, Geology of the Small Isles of Inverness-shire. Mem. Geol. Survey Scotland, 1908; Summ. Progr. Geol. Survey Great Britain, for 1915, 1916, pp. 26–27.

[3] H. S. Washington, Quart. Journ. Geol. Soc., 1907, vol. lxiii, pp. 74–75.

[4] W. Cross, U.S. Geol. Survey, Prof. Paper No. 88, 1915.

[5] R. A. Daly, 'Igneous Rocks and their Origin,' 1914, p. 27.

	Arctic.	British.	W. Med.	Hawaiian.	Average Basalt.
SiO_2 ...	47·49	47·52	47·85	48·69	49·06
Al_2O_3 ...	13·24	16·59	14·90	14·00	15·70
Fe_2O_3 ...	3·81	3·91	2·82	5·03	5·38
FeO ...	8·73	7·05	7·44	8·01	6·37
MgO ...	6·22	6·72	7·32	7·12	6·17
CaO ...	10·23	9·90	8·48	9·00	8·95
Na_2O ...	2·41	2·64	3·63	3·55	3·11
K_2O ...	1·04	0·74	1·67	1·24	1·52
TiO_2 ...	3·81	1·99	4·27	2·29	1·36

From these figures it is clear that the outstanding features of the Arctic basalts are low silica, alumina, and alkalis, and high titanium dioxide, iron oxides, and lime. A peculiarity arising out of these general characters is that many of the basalts contain actual or 'occult' free silica in spite of the low total percentage of that constituent. The western Mediterranean basalts, for example, have more silica and yet are nearly all olivine-bearing rocks.

Turning to details it may be noticed that the basalts with macroporphyritic plagioclase form a series with higher alumina and lower titanium dioxide (cf. Scoresby Sound) than those without noticeable phenocrysts. Throughout the whole series soda is much more abundant than potash. It is interesting, moreover, to find that, except in Iceland, the olivine rocks are those with most potash, though if magnesia and potash are compared they are seen to vary not sympathetically, but rather otherwise. On the other hand, the suggested relation between soda and iron oxides[1] holds with considerable faithfulness. Ferrous oxide is always in excess of ferric, and unusual abundance of the latter is found, not in the rocks with most magnetite, but in those containing most water (above 110° C.), such rocks being generally amygdaloidal.

Among the minor constituents, barium varies with potash, but strontium has no recognizable associate. Phosphorus also varies with potash except in the Hare Island picrite-basalt. This correlation also applies to the basalts of Catalonia, Sardinia, and Linosa, taking each locality by itself, and seems to hold more consistently than the association with iron suggested by Washington (loc. cit., 1907, p. 76). The Wood Bay rocks of Spitzbergen (see p. 206) are relatively richer in phosphorus than the other Arctic basalts, and even more do they differ in the high nickel contents recorded by Dittrich. Among the eight rocks in which nickel was sought by Dr. Harwood it was found in only three, and only

[1] See H. S. Washington, loc. cit., 1907.

in the olivine-basalt of Iceland—containing also a maximum amount of magnesia—was it determinable (0·01 per cent.). Chromium appears to accompany high olivine and hypersthene (normative or present in the enstatite-augite series of pyroxenes). However, the chrome-diopside found by Teall in Franz Josef Land and by Scharizer in Jan Mayen can scarcely be considered a general characteristic of the Arctic basaltic rocks. Vanadium is present in much greater quantity than chromium, but no relation can be detected. It is probably a constituent of the pyroxenes, a remark applying also to the habitat of manganese, which varies throughout the region within narrow limits.

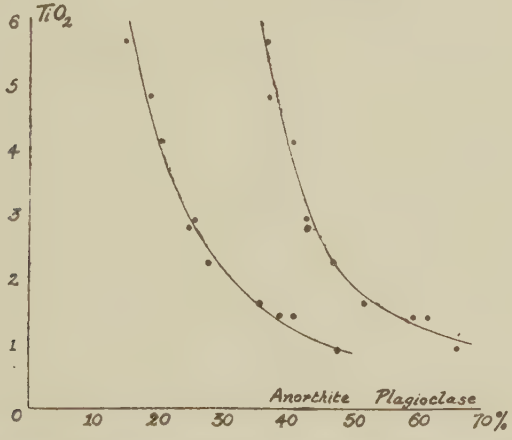


FIG. 2.—Diagram to illustrate the antipathy between titanium dioxide and felspars in the Brito-Arctic saturated basalts. (See p. 216.)

Consideration of titanium dioxide has been left till last, because its abundance and variation from place to place give it a special interest. In a way it may be regarded as a hall-mark of the whole series of rocks with which we are here concerned, as it is of the still more markedly titaniferous basalts of the western Mediterranean. The constituent itself is present chiefly as ilmenite or titaniferous magnetite. In the saturated rocks it shows no signs of being present to any notable extent in pyroxene, whereas in the olivine-bearing rocks the pyroxenes have generally a slight purple tint,[1] which becomes more pronounced in the rocks containing relatively high alkalis. Looking for other mineral associations,

[1] This colour in pyroxenes is almost certainly due to titanium in the presence of soda. The alternative suggestion that it is due to manganese is negatived by chemical evidence.

it is easily seen that in each locality where both saturated and undersaturated rocks occur, the former are richer in titanium dioxide than the latter. Among the saturated rocks those with porphyritic plagioclase contain less titanium dioxide than those without phenocrysts. In a general way titanium dioxide varies inversely as the plagioclase-felspar, but this only holds for the porphyritic rocks if the phenocrysts are left out of account (as, for example, in the basalt from Scoresby Sound). Between felspars and ores the same relation also holds for the basalts of Iceland and the Faroes that have been micrometrically analysed (see pp. 197 and 200). The antipathy between titanium dioxide and normative anorthite and plagioclase is illustrated by the adjoining table and diagram (text-fig. 2, p. 215). The only serious exception is in the Scoresby Sound basalt, which has too much titanium dioxide to fit into the scheme.

Locality.	Titanium Dioxide.	Normative Anorthite.	Normative Plagioclase.
Hare Island ...	5·68 ...	14·65 ...	36·13
Faroe Islands ...	4·83 ...	18·35 ...	36·69
Iceland ...	4·17 ...	20·02 ...	40·46
Scoresby Sound ...	3·98 ...	(37·53) ...	(51·15)
Spitzbergen ...	2·93 ...	25·30 ...	42·59
Mull[1] ...	2·80 ...	24.63 ...	42.42
Franz Josef Land ...	2·29 ...	27·24 ...	46.63
Kuzkin Island ...	1.63 ...	35·58 ...	51·30
Mull[1] ...	1.46 ...	38·92 ...	59·36
Mull[1] ...	1.46 ...	40.87 ...	61·83
Mull[1] ...	0·93 ...	47·82 ...	66.16

It is interesting to find that the saturated basalts of the Pantelleria district also exemplify the same antipathetic relation.[2] The relation may be significant, for in these saturated rocks, plagioclase had almost completed its crystallization while the bulk of the titanium dioxide was still in the magma. The idea thus suggests itself that the basalts may be derivatives from a common type of magma in which some process of partial separation has taken place between plagioclase and the residual magma.

Among the undersaturated basalts the relations are less simple. In the olivine-basalts of Iceland (p. 197) micrometric analysis reveals an antipathy between felspars and ores, but the suggestion made above cannot apply here, for olivine is the first mineral to crystallize, and

[1] See Summ. Progr. Geol. Survey, Great Britain, for 1915, 1916, pp. 26–27.

[2] H. S. Washington, Quart. Journ. Geol. Soc., 1907, vol. lxiii, pp. 74–75 (Norms 6–8).

here is no antipathy between olivine and ores. The alkaline series of undersaturated rocks (Jan Mayen, Wood Bay, &c.) carry a much higher percentage of titanium dioxide than the normal olivine-basalts. Chemically these rocks resemble the titaniferous olivine-basalts of Catalonia, Sardinia, and Linosa, and in each individual locality considered alone the antipathy between titanium dioxide and anorthite is marked.

The geographical distribution of titanium dioxide among the Brito-Arctic basaltic rocks is very curious. Hare Island (5·68 per cent.), Scoresby Sound (3·98 per cent.), Iceland (4·17 per cent.), and Faroe (4·83 per cent.) lie in a belt characterized throughout by high percentages. Towards the north-west one finds a 'diorite-porphyry' at Skreia, Tavnefjord, Jones Sound, having 4·87 per cent., while the older Palaeozoic complexes of alkaline rocks occurring in South Greenland include highly titaniferous types (3·82 per cent. in trachydolerite, Narsak; 4·25 per cent. in 'Ilimausak porphyry'; and 4·41 per cent. in trachydolerite, Nunasarnausak). It thus appears that the belt represents a region underlying which the magmatic sources are particularly titaniferous, either because the materials of the sub-crust have possessed that peculiarity as an original characteristic, or because they have been endowed with it by differentiation taking place during a former period, Devonian or older, of widespread and deep-seated fusion.

Many of the British Tertiary basaltic rocks contain more than 2 per cent. TiO_2, and exceptionally nearly 4 per cent., and on an average they thus compare favourably with the Iceland olivine-basalt (2·36 per cent.). The saturated basalts of Mull (called 'augite-andesite') show a marked falling off, corresponding with a concomitant increase in felspar. On the other side of the belt the richness in titanium dioxide also fades out: to 2·93 per cent. in Spitzbergen, 2·29 per cent. in Franz Josef Land, 1·02 per cent. in Kuzkin Island, and 0·36 per cent. in the basaltic plateau of the Yenisei River.

Turning now to variation in time, it is only in Spitzbergen that a strict comparison between older and younger rocks is possible. There the tendency has obviously been to produce more alkaline types in later times. The trachyandesite of Jan Mayen is a Quaternary or Recent flow from the still active Beerenberg. In Iceland the basaltic flows of modern times[1] do not seem to differ in any marked way from their oldest predecessors, and one can only say that the younger rhyolites seem to be more alkaline than the older, which are associated with andesite

[1] See analysis quoted by H. Rosenbusch, 'Elemente der Gesteinslehre,' 1910, p. 399.

and dacite. Among the other localities no evidence is yet available. The British area is so complex that it is unsafe to generalize, for the later basaltic rocks are sometimes richer, sometimes poorer in their alkali content. However, further south the later rocks of the Atlantic Islands are distinctly of a more alkaline character than their older associates.

Thus in the Atlantic-Arctic region the highly titaniferous belt gives little evidence of a change in time towards an alkaline facies, whereas on each side the rocks become less titaniferous and show a progression in time in the direction of increasing alkalis, wherever younger rocks are exposed.

11. Remarks on the Conception of 'Petrographic Provinces'.

The conception of 'Petrographic Provinces' was suggested by Vogelsang in 1872,[1] and independently by Judd in 1886,[2] and it has since been developed by Harker,[3] Iddings,[4] Washington,[5] and other petrographers. It is clear that a consideration of the rocks of a large area such as that dealt with in this paper implies a study of their variation in three dimensions, two representing the surface of the earth and the third progression in time. In an ideal petrographic province variation in time should follow closely similar lines of evolution at different centres of activity, and variation in place, for any given stage in the parallel lines of evolution, should be slight. The province should, moreover, be bounded by regions having different rock-series, and in time the period of activity should have recognizable limits. Such an ideal province thus demands that similar rocks belonging to similar series (defined by their range of chemical and mineral composition and textures) must be produced in adjacent centres of igneous activity during the same period. This implies that the processes by which the rocks are formed must be similar throughout the province, and that the distribution of rock materials in depth, on which the processes act, must also be similar. One condition alone satisfies these requirements, namely, that all the parts of the province have had a parallel geological history, as regards denudation and

[1] H. Vogelsang, Zeits. Deutsch. Geol. Gesell., 1872, vol. xxiv, p. 525.

[2] J. W. Judd, Quart. Journ. Geol. Soc., 1886, vol. xlii, p. 54.

[3] A. Harker, 'Natural History of Igneous Rocks,' 1909, p. 88; Pres. Add. Sect. C, Rep. Brit. Assoc. for 1911, 1912, p. 372.

[4] J. P. Iddings, Bull. Phil. Soc. Washington, 1892, vol. xii, p. 128; 'Igneous Rocks,' 1913, vol. ii, p. 345.

[5] H. S. Washington, Carnegie Inst. Washington, Pub. No. 57, 1906.

sedimentation, earth movements and former periods of igneous activity. Both denudation and sedimentation affect the distribution of temperature and pressure in depth, the more so because of the influence of radio-activity.[1] Earth movements, according as they compress or stretch the rocks, inhibit or promote fusion, respectively, so that compression allows fusion to begin only at much greater depths than tension. Previous igneous activity may have profoundly affected the nature and distribution of rock material in depth by differentiation (and perhaps also by assimilation) and movement of magmas, so that a renewal of fusion and a repeated differentiation under different circumstances may give rise to rocks quite distinct from those of an earlier period.[2]

It is obvious that the realization of all these factors in a common geological history is likely to be difficult of accomplishment except over comparatively small areas. Denudation and sedimentation merge into each other and overlap in time, so that the boundaries of future provinces become blurred. Earth movements, though often of similar type throughout long belts of the crust, vary greatly in intensity, and so presumably the depth of fusion and degree of differentiation may vary to a corresponding extent from one centre of vulcanism to another. As Harker has pointed out, referring to the British Tertiary province,[3] rocks may belong to two distinct categories: 'The *regional*, distributed over the length and breadth of the province, and the *local*, limited to the neighbourhood of the special centres', where local disturbances have diverged more or less from the prevalent type of movement. As in the British province, so throughout the Arctic region[4] 'the connexion of igneous action . . . with the subsidence of faulted blocks of country is too plain to be missed'. This prevalent movement is doubtless to be correlated with the basalts regionally developed from West Greenland and the off-lying islands to the British area in the south and to the mouth of the Yenisei in the east. Throughout this region, except perhaps at Jan Mayen, basalts belonging to each of the four types distinguished on p. 212 are developed. If no other rocks were associated with these, it might be possible to assert that the region so outlined constitutes a single province, but it would still be necessary to point out that there is a regional variation of composition from the transverse titaniferous belt, to less titaniferous and on the whole more felspathic

[1] See A. Holmes, Geol. Mag., 1916, p. 265.
[2] See J. W. Evans, Geol. Mag., 1916, p. 189.
[3] A. Harker, 'Natural History of Igneous Rocks,' 1909, p. 104.
[4] A. Harker, Pres. Add. Sect. C, Rep. Brit. Assoc. for 1911, 1912, p. 377.

types on either side. When other rocks than normal basalts are considered, however, it becomes clear that to frame a definition of the province in terms of its characteristics and limits in space and time is a difficult and delicate task.

We are, moreover, greatly handicapped by lack of an appropriate nomenclature to apply to such types of provinces as have already been recognized. Terms such as Atlantic and Pacific, alkaline and calc-alkaline, are not suitable, the former pair for geographical reasons, and the latter because series of rocks should be considered rather than individual varieties, stress being laid on the direction and degree of differentiation; in an 'alkaline' volcanic series for example, basalts of undoubted 'calc-alkaline' character may be the most abundant rocks. If for convenience we designate series of rocks by one of their characteristic members, as Rosenbusch has done, we may usefully distinguish andesitic, spilitic, trachydoleritic, and tephritic series. The first of these is associated generally with compressional and upward movements, and the second with compressional and downward movements in regions undergoing sedimentation. The others are generally associated with differential movement of faulted blocks, the possible significance of dominant uplift or subsidence in connexion with depth of fusion and kind of differentiation not yet having been distinguished.

To all four series normal basalts serve as a common foundation, and in general basalts alone do not suffice to determine the series. When we examine the associated rocks, developed at special centres, in order to ascertain the series actually represented in the Arctic region, it becomes clear that two series are present—the andesitic and the trachydoleritic. In the British area the two series have been distinguished by Harker and related respectively to local Pacific and regional Atlantic types of earth movement. In the absence of detailed field evidence in the Arctic localities it is not yet possible to draw a similar conclusion, but one may point out that the area broadly surveyed in this paper lies between two well-marked types of petrographic provinces: the tephritic of the Atlantic Islands and the andesitic of the Pacific borders.

To sum up, the Brito-Arctic region may be described as a composite province, characterized throughout by basaltic rocks with a regional variation of composition, that are for the most part of Tertiary age, but which have forerunners of late Jurassic or Cretaceous age in the east, and modern representatives in Iceland. Among the olivine-free basalts consanguinity is indicated by the antagonistic relation between felspars and titanium dioxide, by the regional variations of both, and by the

usual presence of pyroxene belonging to the enstatite-augite or magnesian-diopside series. The olivine-basalts differ consistently from their saturated associates, with which they have no special relationships. Locally, andesites, dacites, rhyolites, and granite (or granophyre) are developed, and elsewhere more alkaline rocks ranging in composition from olivine-trachydolerite and nepheline-basanite to trachyte and soda-rhyolite are found, the latter series being, as far as the evidence permits of a statement, among the youngest rocks of the region.

This large composite province may be conveniently divided into a number of sub-provinces, each of which corresponds more closely than the whole to the demands of an ideal petrographic province, viz.:

1. The British area, itself composite.

2. The highly titaniferous belt stretching from Hare Island, Disco, and the Nugsuak Peninsula to Scoresby Sound, Iceland, and the Faroes.

3. Jan Mayen, which may perhaps be grouped with the Quaternary volcanoes of Wood Bay, Spitzbergen.

4. Spitzbergen (older rocks), Franz Josef Land, and Kuzkin (or Sibirakov) Island at the mouth of the Yenisei. The plateau basalts of the Yenisei-Tunguska region may also belong to this group, but such descriptions and analyses as are now available are not decisive.

It is interesting to notice that the grouping suggested above is one that would naturally be made geographically (except in 3, which is by time association) from inspection of a bathymetrical chart. The Greenland-Faroes belt lies on a partly submerged ridge separated by deeper water from the British area on the one side, and the localities of sub-province 4 on the other. The latter are nowhere separated from each other or the Siberian mainland by depths exceeding 100 fathoms.

12. Note by Dr. H. F. Harwood on a method of estimating NiO, Cr_2O_3, and V_2O_3 in a single portion of rock.

The methods employed in carrying out the foregoing analyses were essentially those described by Hillebrand,[1] the only modifications being (1) the use of perchloric acid in place of platinum chloride in the estimation of the alkalis,[2] and (2) the estimation of NiO, Cr_2O_3, and V_2O_3 in one and the same portion of rock by the following method:

Five grams of the rock were treated in a platinum basin with sulphuric and hydrofluoric acids until completely decomposed. The whole was

[1] W. F. Hillebrand, The analysis of silicate and carbonate rocks. Bull. U.S. Geol. Survey, 1910, No. 422.

[2] R. G. Thin and A. C. Cumming, Journ. Chem. Soc. Trans., 1915, vol. cvii, p. 361.

then evaporated until the sulphuric acid fumed strongly. After cooling, the mass was digested with hot water and filtered. The residue, mainly calcium sulphate, was ignited, fused with sodium carbonate, the melt taken up with dilute sulphuric acid, and added to the previous solution. Bromine water was now added to oxidize any ferrous iron, the excess removed by boiling, and the solution precipitated by ammonia. Blank experiments on mixtures of known composition showed that this ammonia precipitate carried down with it the whole of the chromium and vanadium present in the rock. The precipitate was well washed, dried, and fused in a nickel crucible with caustic soda and sodium peroxide, the melt extracted with water, the solution boiled, filtered, and the vanadium and chromium in the filtrate estimated by Hillebrand's method (precipitation with mercurous nitrate, &c.). The nickel was estimated in the filtrate from the ammonia precipitate by concentrating this to a small bulk and adding a solution of dimethylglyoxime and (if necessary) ammonia to alkaline reaction. After standing overnight, the scarlet precipitate was filtered off, dissolved in hydrochloric acid, the solution well boiled, and the nickel re-precipitated with dimethylglyoxime and ammonia. The precipitate of nickel dimethylglyoxime was filtered off on a platinum Munro crucible and weighed.

Explanation of Plates VI and VII.

Plate VI. (Ordinary Light. Magnification × 25, except in fig. 1 which is × 45.)

Fig. 1.—*Basalt* (No. 1554), Hare Island, West Greenland, Microporphyritic labradorite in a base of labradorite-laths, augite-granules, and magnetite and ilmenite. (Analysis, p. 183.)

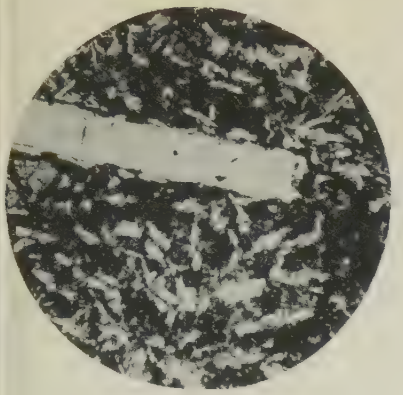
Fig. 2.—*Olivine-Basalt* (No. 1555), Hare Island. Microphenocryst of olivine and minute laths of labradorite in a base of augite and iron-ores.

Fig. 3.—*Melanocratic Olivine-Trachydolerite* or *Felspathic Augitite* (No. 1553), Hare Island. Idiomorphic phenocrysts of brown to purple augite, with microphenocrysts of olivine (under the crack, on the left of the field) and laths of bytownite in a dark-brown base. (Analysis, p. 187.)

Fig. 4.—*Porphyritic Basalt* (No. 1560), South side of Scoresby Sound, East Greenland. Phenocrysts of bytownite in a fine-grained intersertal groundmass broken by amygdales. (Analysis, p. 189.)

Fig. 5.—*Sub-ophitic Basalt* (No. 387), Holmatindur, Eskifjord, Iceland. Labradorite-laths, enstatite-augite, and large skeletal crystals of ilmenite. (Analysis, p. 192.)

Fig. 6.—*Porphyritic Basalt* (No. 383), Eskifjord, Iceland. Phenocrysts of bytownite mantled with labradorite in an intergranular groundmass rich in ilmenite.



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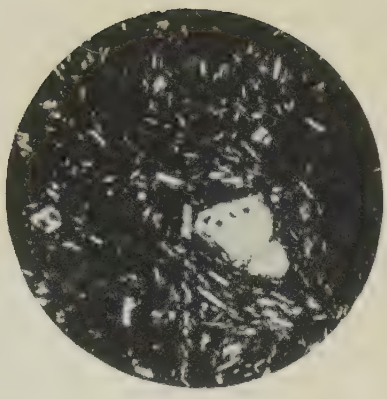

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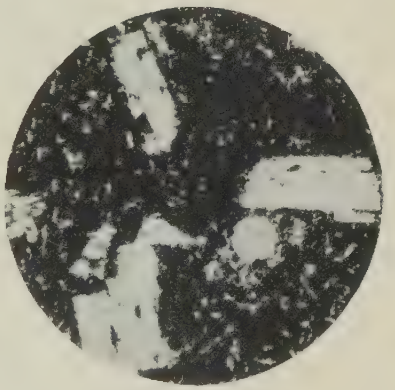

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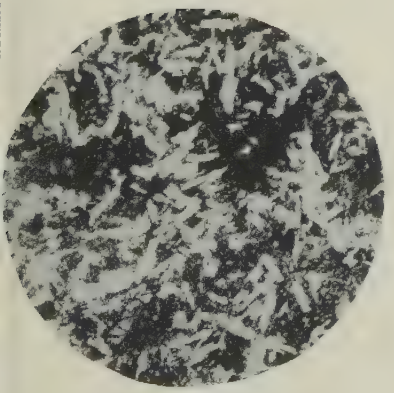

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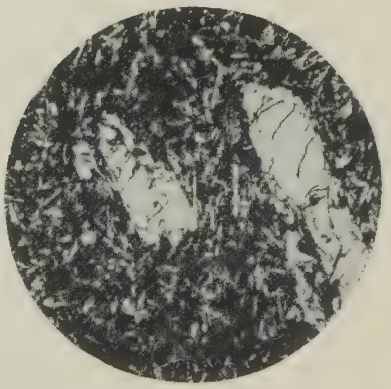

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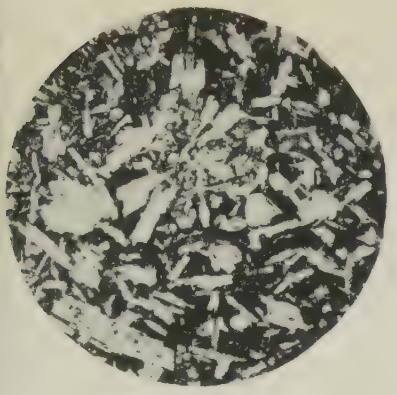

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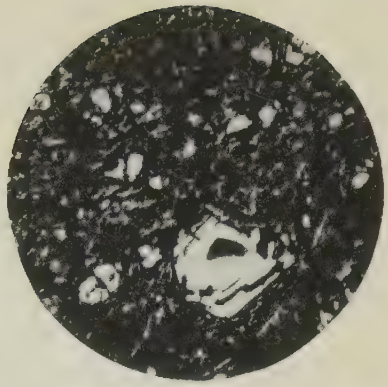

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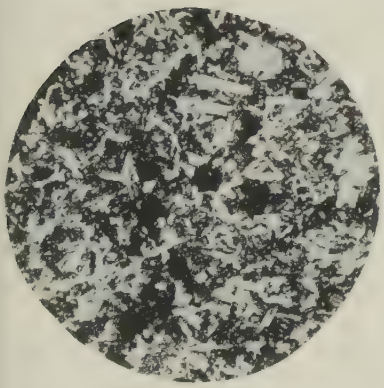

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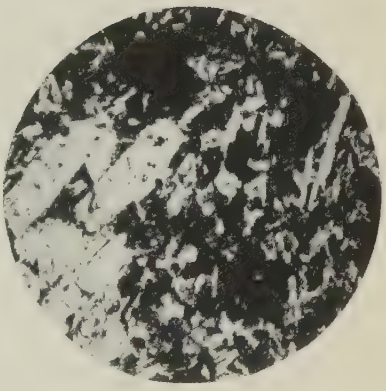

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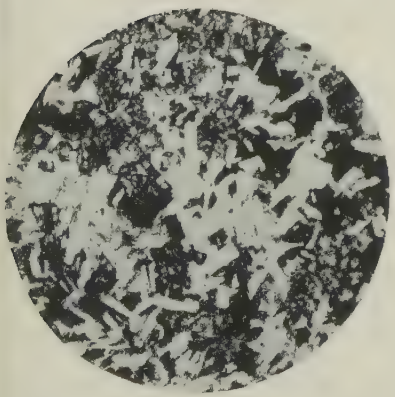

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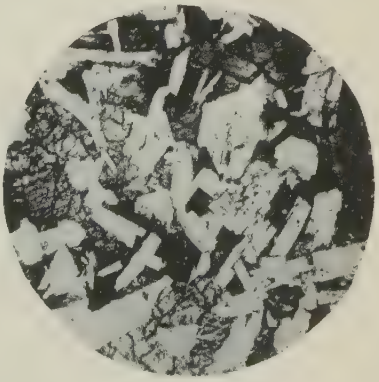

6

A. Holmes: Basaltic Rocks of the Arctic Region.

Plate VII. (Ordinary light. Magnification × 25, except in fig. 2 which is × 45.)

Fig. 1.—*Olivine-Basalt* (No. 837), Grundafjord, West Peninsula, Iceland. The rock contains porphyritic olivines not visible in the field, which shows the ophitic texture and peculiar vesicular character of the rock. The minerals seen are bytownite, augite (with olivine-nuclei), and ilmenite. (Analysis, p. 196.)

Fig. 2.—*Olivine-Trachyandesite* (No. 4208), Mary Muss Bay, Jan Mayen. Microphenocrysts of corroded olivine and of smaller augites in a fine groundmass containing andesine. The rock also contains idiomorphs of andesine too large to be shown in the field. (Analysis, p. 204.)

Fig. 3.—*Sub-ophitic Basalt* (No. 385), Waags-fjord, Suderöe, Faroe Islands. Labradorite, enstatite-augite, and ilmenite. Apatite inclusions can be seen in some of the felspars. (Analysis, p. 201.)

Fig. 4.—*Porphyritic Basalt* (No. 386), Thorshavn, Stromöe, Faroe Islands. Similar to No. 385, but contains phenocrysts of calcic labradorite and large crystals of ilmenite.

Fig. 5.—*Ophitic Basalt* or *Dolerite* (No. 4209), Sassendal, Central Spitzbergen. Contains labradorite enstatite-augite, titaniferous magnetite, and glass. (Analysis, p. 208.)

Fig. 6.—*Ophitic Basalt* or *Dolerite* (No. 311), Old Depot, Hooker Island, Franz Josef Land. Constituents as in fig. 5, but with coarser grain. (Analysis, p. 210.)

The photomicrographs here produced were prepared by Mr. G. S. Sweeting, of the Geology Department of the Imperial College, from thin sections which, with a large number of others, were made for this investigation by Mr. E. J. Tallin (of the same Department). For the valuable assistance thus afforded I wish in conclusion to express my thanks.

The relation between different laws of twinning that result in the same twin-crystal.

By John William Evans, LL.B., D.Sc., F.G.S.

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[Read June 20, 1916.]

IN the following notes I have endeavoured to give in a convenient and simple form a complete account of the relations connecting different twinning-laws or operations, which, when applied to the same crystal-structure, produce indistinguishable results.

A rigorous analysis of the possible relations between the compound structures of twin-crystals, based on the principles of the equality of the structural distances in the plane of composition, will be found in the author's papers, 'The geometry of twin-crystals' (Proc. Roy. Soc. Edinburgh, 1912–1913, vol. xxxii, pp. 416–432, 433–457) and 'Die Geometrie der Zwillingskrystalle' (Zeits. Kryst. Min., 1913, vol. lii, pp. 327–371). See also the paper 'Twin-planes and cross-planes' in this Magazine (1910, vol. xv, pp. 390–397).

I. *Twin-operations.*—A twin-crystal may be defined as a compound crystal with one or more twin-planes. A twin-plane is a plane which possesses the character that every line in it stands in exactly the same relation to two differently oriented crystal-structures of the same substance. The normal to a twin-plane is a twin-axis. It also has the same relation to both structures.

The connexion between the two portions of a twin-crystal may be conveniently represented by considering that one portion of a simple crystal has been subjected to one of the following 'twinning-operations'

(1) A rotation round a line, the twin-axis, through half a circle; or as I prefer to express it, 'a reversal relatively to a line'. This may be described as 'line-twinning' or 'rotation-twinning', and denoted by the letter L. The plane at right angles to the line is here the twin-plane.

(2) A reflection on a plane, the twin-plane; or a 'reversal relatively to a plane'. This may be termed 'plane-twinning' or 'reflection-twinning', and denoted by P. The normal to the plane is the twin-axis.

(3) Inversion[1] through a point; or a 'reversal relatively to a point'. Here the structure is completely reversed, so that every plane, line, or point is shifted to the opposite side of a central point which remains unmoved. This may be referred to as 'point-twinning' or 'inversion-twinning', and denoted by I. Here every plane has the characters of a twin-plane, and every line that of a twin-axis.

(4) Rotation round a line through a quarter of a circle.

(5) Rotation round a line through a sixth of a circle.

The first three, however, of these operations suffice to explain every twin-crystal. These essential twinning operations are best illustrated in the twins of quartz and pyrargyrite referred to on pp. 235–237, but examples will be found throughout this communication.

II. *Twinning in the absence of symmetry.*—If there be no symmetry in the untwinned crystal, or none related to a twin-axis in any of the ways hereafter described, a twin-crystal can be explained by only one twinning operation, and this must be one of the first three mentioned above.

FIG. 1.

FIG. 2

FIG. 3.

FIG. 4

Figs. 1 to 4 illustrate the three modes of twinning when they occur in a crystal without symmetry. Each diagram may be considered as a stereographic (or gnomonic) projection showing a single face constituting a 'form'. If the face is on the *upper* side of the crystal, the projection point is marked by the centre of a plus sign, while if it is on the *under* side, its projection is indicated by the centre of a minus sign in the place where the projection of a *parallel* face on the *upper* side would have been situated—*not* that of the upper face which is the reflection of the lower face in the plane of projection according to the usual practice

[1] This must be distinguished from inversion as defined in the geometrical method of Stubbs and Ingram.

in the case of stereographic projection.[1] In other words, the procedure in gnomonic projection is followed. The left-hand diagram (fig. 1) shows the orientation of that portion of the twin-crystal which is considered to be unaffected by the twinning operations; the next (fig. 2) gives the orientation of the other portion after rotation through a half circle round the normal to the plane of projection. Figs. 1 and 2 represent, therefore, the orientation of the two portions of a crystal with rotation-twinning. Fig. 3 gives the orientation of the second portion after reflection on the plane of projection. Consequently, figs. 1 and 3 show the relative orientation of the two portions of a twin-crystal with reflection-twinning. Fig. 4 shows in like manner the orientation of the second portion after inversion-twinning, so that in this case figs. 1 and 4 illustrate the relative orientation of the two parts of the twin.

The result is different in the three cases, but in each the plane of projection is a twin-plane and its normal a twin-axis, though in the last any other plane and its normal might be taken as twin-plane and axis.

The numeral '1' of the symbols accompanying the diagrams indicates that the normal to the plane of projection is *not* an axis of symmetry. The capital 'U' (unilateral) shows that it does not lie in a plane of symmetry, and the small 'u' (uniterminal) that opposite directions in the normal are not equivalent to one another, and have therefore different physical characters. The letters 'L', 'P', and 'I' denote, as already stated, twinning by rotation, reflection, and inversion respectively. The occurrence of inversion-twinning is indicated in the diagram by a small circle round the centre of the larger one.

If, on the other hand, there be some form of symmetry present in the untwinned crystal, a twin-crystal may in many cases be described by any one of two or more twinning-operations. These are said to be 'equivalent' to one another.

III. *Axis of trigonal symmetry as twin-axis.*—If there be only an axis of trigonal symmetry, the three essential modes of twinning, with this as twin-axis, will still give different results. In the case of rotation-twinning, however, the same result will be obtained by rotation through one-sixth of a circle as by rotation through half a circle.

In figs. 5, 6, 7, and 8 the fact that the normal to the plane of projection is an axis of trigonal symmetry is indicated by the numeral '3' in the symbol. Here each form consists of the three faces shown in the diagrams.

[1] J. W. Evans, A modification of the stereographic projection. Mineralogical Magazine, 1910, vol. xv, pp. 401–402.

3 Uu
FIG. 5.

3 Uu L
FIG. 6.

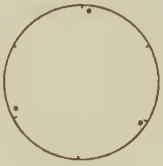
3 UuP
FIG. 7.

3 Uu I
FIG. 8.

IV. *Centre of Symmetry.*—If a centre of symmetry be present, every axis of rotation-twinning is also an axis of reflection-twinning, and vice versa. Conversely, if the same line be an axis of both rotation- and reflection-twinning, and these are equivalent to one another, the untwinned crystal must possess a centre of symmetry.

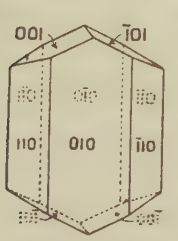
1 Uc
FIG. 9.

1 Uc L P
FIG. 10.

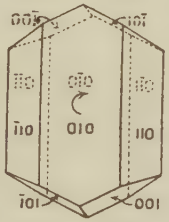


3 Uc
FIG. 11.

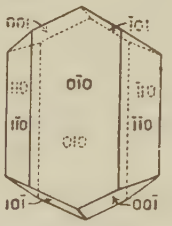
3 Uc L P
FIG. 12.



1 Uc
FIG. 13.



1 Uc L
FIG. 14.



1 Uc P
FIG. 15.

Figs. 9 and 10 are projections, similar to those already described (p. 225), of a single crystal-form. They illustrate the twinning of a crystal possessing a centre of symmetry. Here every face of a form is accompanied by an equivalent opposite parallel face, and both of these faces are represented in the projection not by plus and minus signs but by a single dot. In the symbols, the letter 'c' indicates the presence of a centre of symmetry, and the conjunction of the letters 'L P' that the same configuration results from rotation round the twin-axis as from reflection on the twin-plane.

In figs. 13, 14, and 15, the same relation is illustrated by orthogonal projections on the brachypinakoid of the two component parts of a crystal of plagioclase showing albite-twinning. Fig. 13 shows the orientation of the portion to which no twinning operation has been applied; fig. 14, the result of rotation round the normal to a brachypinakoid face, and fig. 15, that of reflection on the same face. The indices demonstrate the difference between these two operations, which, however, produce exactly the same apparent result. The edges of the under crystal faces are shown by interrupted lines, and their indices are distinguished in the same manner.

Figs. 11 and 12 illustrate the twins of phenakite on the basal plane. Here there are a trigonal axis and a centre of symmetry.

If there be a centre of symmetry, inversion-twinning is impossible.

V. *Line of Symmetry.*—A line of symmetry[1] may also result in the presence of equivalent twinning-operations.

FIG. 16

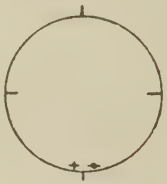


FIG. 17

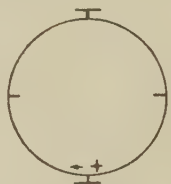


FIG. 18

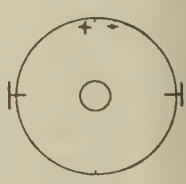


FIG. 19

(1) If there be an axis of rotation-twinning, or of reflection-twinning, or of both rotation- and reflection-twinning at right angles to a line of symmetry, there will be another axis of twinning of the same nature at right angles both to the line of symmetry and to the first twin-axis. The simplest examples would occur in twins of crystals which, like cane-sugar, have no symmetry except an axis of digonal symmetry.

This is illustrated in figs. 16, 17, and 18, where the letter 'h' denotes the presence of a line of symmetry in the plane of projection, in the position indicated in the diagrams by two short radial lines *inside* the circle. In 1 Uh L, fig. 17, the crystal has been rotated by the twinning operation round the normal to the plane of projection, which thus

[1] It is convenient to use the term 'line of symmetry' to include axes with an *even* number of symmetry—digonal, tetragonal, or hexagonal—but not those with 'contra-directional' digonal or hexagonal symmetry, as defined on p. 238. A line of symmetry is analogous in many respects to the normal to a plane of symmetry; which is a line of symmetry, when a centre of symmetry is present; and, in its absence, an axis of contra-directional digonal or hexagonal symmetry.

becomes an axis of rotation-twinning. The same result is obtained by a rotation round an axis parallel to the plane of projection at right angles to the line of symmetry. The position of this second axis of rotation-twinning is indicated by two short radial lines *outside* the circle. In 1 Uh P, fig. 18, the crystal has been reflected in the plane of projection, the normal to which has become a twin-axis of reflection-twinning. The same result follows from a reflection about a plane at right angles to the plane of projection, and passing through the line of symmetry. Its normal, which lies in the plane of projection and is at right angles to the line of symmetry, is therefore a second axis of reflection-twinning, the position of which is shown by two short radial lines, outside the circle, terminated by two longer lines at right angles. Fig. 19, 1 Uh I, will be considered later.

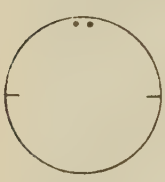
The case where there is also a centre of symmetry and each twin-axis is accordingly an axis both of rotation and reflection-twinning, is illustrated by the Karlsbad-twins of orthoclase. Here there are two axes of twinning, one the vertical axis, the other the normal to the orthopinakoid. Both are at right angles to the ortho-axis, which is here an axis of digonal symmetry and therefore a line of symmetry, and lie in the clinopinakoid, which is a plane of symmetry; and they are at right angles to each other.

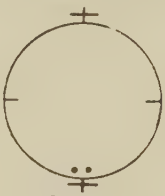
Figs. 20 and 21, 1 Bc and 1 Bc L P, are projections of the character, already described (p. 225), of a single crystal-form in the component parts of a twin of the Karlsbad-type; that is to say, with two twin-axes at right angles to a line of symmetry and lying in the plane of symmetry. One of these twin-axes is at right angles to the plane of projection, and the other parallel to it. In the symbols the letter 'B' indicates that the normal to the plane of projection is parallel to a plane of symmetry, and the letters 'L P' that it is an axis of both rotation- and reflection-twinning. The position of the other axis of both rotation- and reflection-twinning, which is parallel to the plane of projection, is shown by two crosses outside the circle. Both twin-axes are seen to be at right angles to a line of symmetry parallel to the plane of projection.

Orthogonal projections of a crystal of orthoclase on the plane at right angles to the vertical axis are shown in figs. 24 to 28. Fig. 24 corresponds to fig. 20, and figs. 25–28 to fig. 21. Figs. 25–28 show how the same configuration may be brought about by different operations, which can be inferred from the indices of the faces shown. Fig. 25 shows the positions of the faces after (*a*) rotation on the vertical axis; fig. 26 after (*b*) reflection on the horizontal plane to which it is normal;

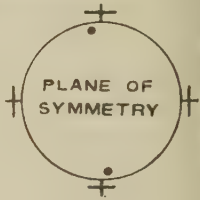
fig. 27 after (*c*) rotation on the normal to the orthopinakoid; and fig. 28 after (*d*) reflection on the orthopinakoid. All these twinning-operations produce an indistinguishable result.

Figs. 22 and 23 are projections on the plane at right angles to the digonal axis—that is to say, on the plane of symmetry, the clinopinakoid —of the same form in the same twin-structure as in figs. 20 and 21. In the same manner, figs. 29 to 33 are orthogonal projections on the

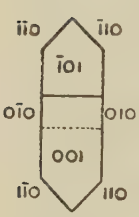

1 Bc
FIG. 20.


1 Bc L P
FIG. 21.

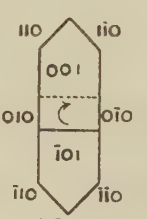
2 Uc
FIG. 22.



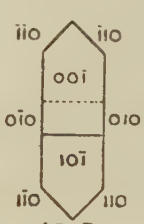
2 Uc L' P'
FIG. 23.



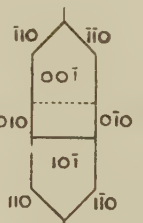
1 Bc
FIG. 24.



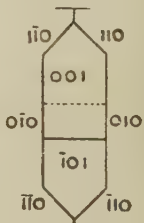
1 Bc L
(a) FIG. 25.



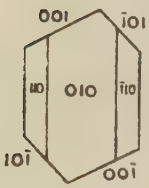
1 Bc P
(b) FIG. 26.



1 Bc L'
(c) FIG. 27.

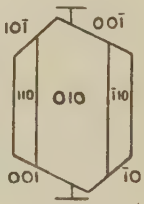


1 Bc P'
(d) FIG. 28.



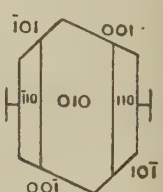
2 Uc
FIG. 29.

2 Uc L'
(a)
FIG 30



2 Uc P'
(b)
FIG. 31.

2 Uc L''
(c)
FIG. 32.



2 Uc P''
(d)
FIG. 33.

clinopinakoid corresponding to figs. 24 to 28. The letters L' P' and L'' P'' indicate the presence of axes of both rotation- and reflection-twinning lying in the plane of projection.

If (as in plagioclase) there were no symmetry except the centre of symmetry, there could be only one twin-axis in the same simple twin, corresponding either to (*a*) and (*b*) or to (*c*) and (*d*). There are in fact two different kinds of twins in triclinic felspars corresponding to the

Karlsbad-twin of orthoclase. In plagioclase the twin-axis is usually the vertical axis, and in anorthoclase, apparently, the normal to the macropinakoid.

If the centre of symmetry were absent and only the axis of digonal symmetry remained, the two twin-axes would both be either axes of rotation-twinning (*a*) and (*c*), or both axes of reflection-twinning (*b*) and (*d*), but not axes of both kinds of twinning. We shall see later that if only the plane of symmetry remained, one of the twin-axes would be an axis of rotation-twinning and the other of reflection-twinning, so that (*a*) and (*d*) would be equivalent twinning-operations, and so would (*b*) and (*c*), but the two former would not give the same result as the two latter.

(2) If a line of symmetry be an axis of reflection-twinning, the twin-crystal can also be explained by inversion-twinning, and, conversely, if a twin-crystal can be explained by inversion-twinning every line of symmetry is an axis of reflection-twinning.

This relation is illustrated by figs. 16 and 19 (1 Uh and 1 Uh 1), p. 228, where the line of symmetry and the axis of reflection-twinning, which coincides with it, are parallel to the plane of projection.[1]

The same relation is also shown in figs. 34 to 45, and 53 to 58, where the lines of symmetry and axes of reflection-twinning are normal to the plane of projection. In figs. 40 to 45 they occur both normal and parallel to that plane.

Here the numerals 2, 4, and 6, indicate that the normal to the plane of projection is a digonal, tetragonal, or hexagonal axis of symmetry.

There are twins of eulytine, diamond, and tetrahedrite, which can be described as twins by reflection on the cube faces. The crystallographic axes are therefore axes of reflection-twinning. As they are at the same time lines of symmetry, being digonal axes, the twins may also be explained by inversion-twinning, so that every point of one component portion corresponds to an exactly similar point of the other on the opposite side of the point of inversion. See p. 239, and figs. 79 to 82.

Another familiar case, the inversion- and reflection-twins of quartz, is described later. See page 237, and figs. 59, 62, 63, 66.

A line of symmetry cannot be an axis of rotation-twinning.

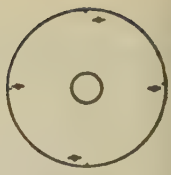
VI. *Plane of symmetry.*—A plane of symmetry will also give rise to equivalent twin-operations.

[1] The manner in which a line of symmetry and an axis of reflection-twinning are respectively indicated in these projections is explained on pp. 228, 229.

2 Uu
FIG. 34.

2 Uu P I
FIG. 35.

4 Uu
FIG. 36.


4 Uu PI
FIG. 37.

6 Uu
FIG. 38

6 Uu P I
FIG 39

2 Uh
FIG. 40.

2 Uh P I
FIG. 41.

4 Uh
FIG. 42.

4 Uh P I
FIG. 43.

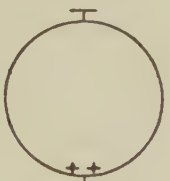
6 Uh
FIG. 44

6 Uh P I
FIG. 45.

(1) If there be an axis of rotation-twinning parallel to a plane of symmetry, there will be parallel to the same plane of symmetry an axis of reflection-twinning at right angles to the axis of rotation-twinning: and, vice versa, an axis of reflection-twinning parallel to a plane of symmetry implies the existence of an axis of rotation-twinning at right angles to it and parallel to the same plane of symmetry. Examples may occur in any crystal possessing a plane of symmetry but no centre of symmetry; for instance, clinohedrite (see figs. 46 to 48). In these figures there is a plane of symmetry at right angles to the plane of projection, and therefore parallel to its normal. Figs. 46 and 47 represent the components of a twin in which the normal to the plane of projection is an axis of rotation-twinning parallel to a plane of symmetry. There is accordingly also an axis of reflection-twinning parallel to the same plane of symmetry and at right angles to the axis of rotation-twinning, and therefore parallel to the plane of projection. Figs. 46 and 48 represent the components of a twin in which the normal to the plane of projection is an axis of reflection-twinning, and there is an axis

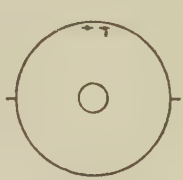
of rotation-twinning at right angles to it, parallel to the plane of projection. Both twin-axes are parallel to the plane of symmetry.

1 Bu
FIG. 46.



1 Bu L
FIG. 47.

1 Bu P
FIG. 48.



1 Bu I
FIG. 49

If there be an axis of both rotation- and reflection-twinning parallel to a plane of symmetry, there will be another axis of the same kind of twinning parallel to the same plane of symmetry and at right angles to the first axis. This case is, however, the same as the case of a similar axis of twinning at right angles to a line of symmetry, for a centre of symmetry must be present (see p. 227), and when that is the case every plane of symmetry has a line of symmetry at right angles to it. It has already been illustrated by the projections of Karlsbad twin-crystals in figs. 20 to 33. If the centre of symmetry and line of symmetry did not exist, but only the plane of symmetry, each axis would, as stated on p. 231, be an axis of only one mode of twinning, and while one would be an axis of rotation-twinning, the other would be an axis of reflection-twinning, as in figs. 46 to 48.

(2) If the normal to a plane of symmetry be an axis of rotation-twinning, the same twin-crystal can be formed by inversion-twinning; and if a twin-crystal can be explained by inversion-twinning, the normal to every plane of symmetry is an axis of rotation-twinning (figs. 46, 49, 53 to 58, 67, 70, 71, 74, 79 to 90). Thus the twins of eulytine, diamond, and tetrahedrite, already referred to (pp. 231, 239, and figs. 79 to 82), possess axes of rotation-twinning normal to the six planes of symmetry parallel to the rhombic-dodecahedron faces.

The normal to a plane of symmetry cannot be an axis of reflection-twinning. The similarity of the relations between equivalent twinning-operations due to the presence of a line or a plane of symmetry, may be seen at a glance in the following table, which also shows how closely the normal to a plane of symmetry is comparable to a line of symmetry.

Line of Symmetry.

If there be an axis of *rotation-*, or of *reflection-twinning*, or of *both*, at right angles to a line of symmetry, there will be another axis of *rotation-*, or *reflection-twinning* respectively, or of *both*, at right angles to the line of symmetry and to the first axis of twinning.

If a line of symmetry be an axis of reflection-twinning, the twin-crystal is an inversion-twin.

In an inversion-twin, every line of symmetry is an axis of reflection-twinning.

The Normal to a Plane of Symmetry.

If there be an axis of *rotation-*, or of *reflection-twinning*, or of *both*, at right angles to the normal to a plane of symmetry, there will be an axis of *reflection-*, or *rotation-twinning* respectively, or of *both*, at right angles to the normal to the plane of symmetry and to the first axis of twinning.

These twin-axes will of course be parallel to the plane of symmetry.

If the normal to a plane of symmetry be an axis of rotation-twinning, the twin-crystal is an inversion-twin.

In an inversion-twin, every normal to a plane of symmetry is an axis of rotation-twinning.

VII. *Axis of simple, or 'co-directional', n-fold symmetry.*—If there be an axis of rotation-, or of reflection-twinning, or of both, at right angles to the axis of *n*-fold symmetry, it will be one of *n* twin-axes of the same nature at right angles to the same axis of symmetry and making equal angles with one another. This is illustrated in figs. 50 to 52.

FIG. 50.

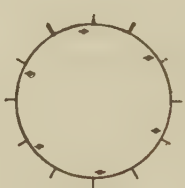


FIG. 51.

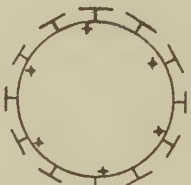


FIG. 52.

These figures show an axis of hexagonal symmetry. Figs. 50 and 51 represent two components of a twin-crystal where there are six axes of rotation-twinning at right angles to the hexagonal axis and parallel to the plane of projection; and figs. 50 and 52 represent the two components of a twin-crystal where there are six axes of reflection-twinning in a similar position. The letters L′ and P′ indicate the presence of these axes of rotation- and reflection-twinning respectively, the positions of which are shown in the projection in the manner already described on p. 229.

The relations described in Section V (1), pp. 228–231, are of course a special case of those dealt with under this Section.

VIII. *Axis of simple, or 'co-directional', n-fold symmetry, with n lines of symmetry at right angles to it.*—If an axis of simple *n*-fold

symmetry, with n lines of symmetry at right angles to it, be an axis of rotation-, or of reflection-twinning, or of both, there will be n axes of twinning of the same nature at right angles to each line of symmetry and to the axis of n-fold symmetry (combination of V (1) and VII).

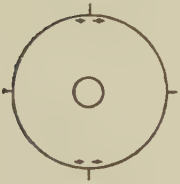
These relations are illustrated by figs. 40 to 45, 59 to 61, 63 to 65, and 75 to 78, p. 236, which will be considered in more detail later.

IX. *Axis of simple, or 'co-directional', n-fold symmetry, with n-planes of symmetry passing through it.*—If an axis of simple n-fold symmetry be an axis of rotation-, or of reflection-twinning, or both, there will be an axis of reflection-, or rotation-twinning respectively, or both, at right angles to the axis of symmetry, parallel to every plane of symmetry. (Combination of VI (1) and VII.)

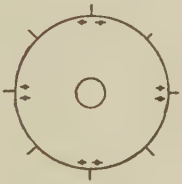
2 Bu
FIG. 53.

4 Bu
FIG. 55.

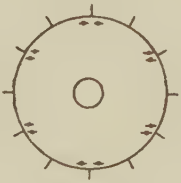
6 Bu
FIG. 57.



2 Bu P I
FIG. 54.



4 Bu P I
FIG. 56.



6 Bu P I
FIG. 58.

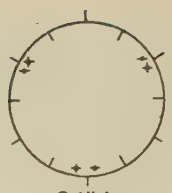
This is illustrated by figs. 53 to 58, and by figs. 67 to 69, 71 to 73, and 75 to 78, which likewise will be considered in more detail later.

If the axis of symmetry be an axis both of rotation- and of reflection-twinning, there must be a centre of symmetry, and therefore a line of symmetry at right angles to every plane of symmetry, so that the case coincides with one already considered in VIII.

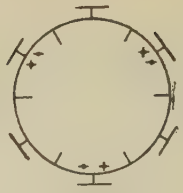
In all the twin-crystals included in Sections VII, VIII, and IX, the principal axis of symmetry has the same orientation in the two component parts of the twin. This is also the case in all inversion-twins.

These relations are well illustrated by the twin-crystals of quartz, pyrargyrite (with proustite), and calcite, that fall in this category. They

3 Uh
FIG. 59.



3 Uh L
FIG. 60.



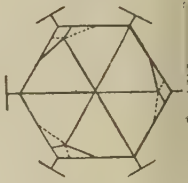
3 UhP.
FIG. 61

3 Uh I
FIG. 62.

3 Uh
FIG. 63.

3 Uh L
FIG. 64.

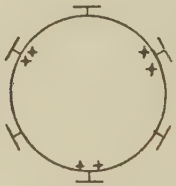
3 UhP
FIG. 65.



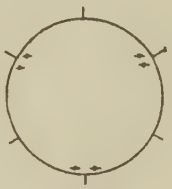
3 Uh I
FIG. 66.

Figs. 59–66.—Quartz.

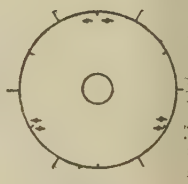
3 Bu
FIG. 67.



3 Bu L
FIG. 68.

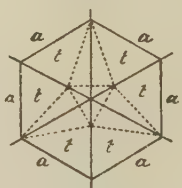


3 BuP
FIG. 69.

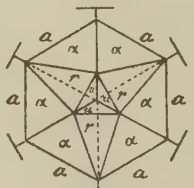


3 Bu r
FIG. 70.

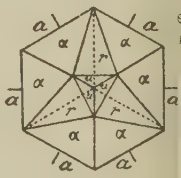
3 Bu
FIG. 71.



3 Bu L
FIG. 72.

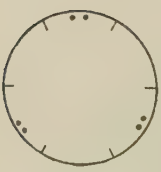


3 BuP
FIG. 73.

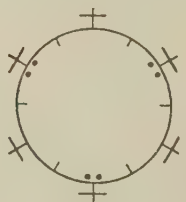


3 Bu I
FIG 74.

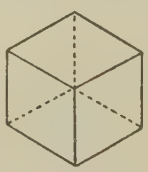
Figs. 67–74.—Pyrargyrite or Proustite.



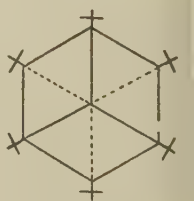
3 Bc
FIG. 75.



3 Bc L P
FIG. 76



3 Bc
FIG. 77.



3 Bc L P
FIG. 78.

Figs. 75–78.—Calcite.

are shown in figs. 59 to 74, and the close analogy between them will be seen from the table which follows.

Figs. 59 to 62, 67 to 70, 75 and 76, are stereographic projections of the character already described (p. 225), on the basal plane. Figs. 63 to 66, 71 to 74, 77 and 78, are orthogonal projections on the basal plane.

Most of these twins are described by Prof. Lewis in his 'Treatise on Crystallography' (1899, pp. 514–515, 519–523, 527), those of pyrargyrite and proustite by Sir Henry Miers (this Magazine, 1888, vol. viii, pp. 73–92). Their relations to one another are shown in the following table.

Symmetry.	*Quartz.*	*Pyrargyrite.*	*Calcite.*
	Axis of threefold symmetry, the principal axis. Three lines of symmetry (digonal axes) at right angles to the principal axis. These are the lateral crystallographic axes.	Axis of threefold symmetry, the principal axis. Three planes of symmetry passing through the principal axis. Their normals are the lateral crystallographic axes.	Axis of threefold symmetry, the principal axis. Three lines of symmetry (digonal axes) at right angles to the principal axis. These are the lateral crystallographic axes and they are normal to planes of symmetry passing through the principal axis.
Types of twin-crystals in which the principal axes of the two components are parallel.	(1) The principal axis is an axis of rotation-twinning; there are three other axes of rotation-twinning at right angles to the principal axis and to the lines of symmetry.[1] (3 Uh, 3 Uh L.)	The principal axis is an axis of rotation-twinning; there are three axes of reflection-twinning at right angles to the principal axis, and parallel to the planes of symmetry.[1] (3 Bu, 3 Bu L.)	The principal axis is an axis of rotation- and reflection-twinning; there are also three axes of rotation- and reflection-twinning at right angles to the principal axis and to the lines of symmetry, and parallel to the planes of symmetry.[1] (3 Bc, 3 Bc LP.)
	(2) The principal axis is an axis of reflection-twinning; there are also three other axes of reflection-twinning at right angles to the principal axis and to the lines of symmetry (3 Uh, 3 Uh P.)	The principal axis is an axis of reflection-twinning; there are also three axes of rotation-twinning at right angles to the principal axis, and parallel to the planes of symmetry. (3 Bu, 3 Bu P.)	The corresponding twin-crystal is that already described.
	(3) Inversion-twin The three lines of symmetry are axes of reflection-twinning. (3 Uh, 3 Uh I.)	Inversion-twin. The normals to the three planes of symmetry are axes of rotation-twinning. (3 Bu, 3 Bu I.)	As there is a centre of symmetry, no inversion-twinning is possible.

[1] These twin-crystals may also be formed by rotation round the principal axis through one-sixth of a circle. (See p. 240.)

X. *Axis of contra-directional* n*-fold symmetry.*—(Rotation-inversion axis of Hilton);[1] that is to say, an axis of symmetry in a crystal without central symmetry, such that a rotation round it through an angle $\frac{2\pi}{n}$ brings every line in the structure into coincidence with the former position of an equivalent line, but, in the case of a line having different properties in opposite directions, with its directions reversed. Here n must be even[2]—2, 4, or 6. See figs. 79, 81, 83, 85, 87, 89, 91. In the symbols accompanying the figures, such an axis is indicated by k. Examples of contra-directional axes are, the ortho-axis of clinohedrite, 2 Uk, the lateral axes of hemimorphite, 2 Bk, the crystallographic axes of eulytine and tetrahedrite, 4 Bk, and the vertical axis of chalcopyrite, 4 Bk, and of benitoite, 6 Bk; also the vertical axes 4 Uk and 6 Uk in the classes that differ from the last two minerals by the absence of vertical planes of symmetry, but of which no examples are known.

If there be an axis of rotation- or reflection-twinning at right angles to an axis of contra-directional symmetry, there will be in all $n/2$ axes of rotation-twinning and $n/2$ axes of reflection-twinning at right angles to the axis of symmetry, alternating and making equal angles with one another. Examples are given under XI and XII, where the axis of contra-directional symmetry itself is also an axis of twinning, which is not the case when the lateral twin-axis is neither at right angles nor parallel to a line of symmetry, or to a plane of symmetry passing through the contra-directional axis of symmetry.

The relations described in this Section include those stated in VI (1) for in the absence of a centre of symmetry, a normal to a plane of symmetry is always a contra-directional axis of n-fold symmetry, in which $n/2$ is odd, in other words n is 2 or 6. This is illustrated by figs. 83, 85, 87, 89.

XI. *Axis of contra-directional* n*-fold symmetry, where* n/2 *is even, and where there are* n/2 *lines of symmetry passing through the axis, alternating with* n/2 *planes of symmetry and bisecting the angles between them.*—In

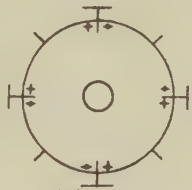
[1] H. Hilton, this Magazine, 1907, vol. xiv, pp. 261-263.

[2] In a simple, or co-directional, axis of symmetry, there is, on rotation through a portion of a circle, coincidence, not only of every line of the crystal with the former position of an equivalent line, but also of the directions in them. A contra-directional axis, in which $n = 4$ or 6 is also a co-directional axis with $n = 2$ or 3, as the case may be, but a contra-directional axis in which n is 2 is not a co-directional axis. If the character of an axis of symmetry is not expressly mentioned, it must be assumed that a simple or co-directional axis is intended.

this case n must be 4, and the contra-directional axis is represented by the symbol 4 Bk (fig. 79).

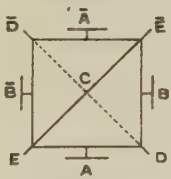
If in such a crystal the axis of contra-directional symmetry be an axis of reflection-twinning, the $n/2$ lines of symmetry at right angles to it will be axes of reflection-twinning, and the $n/2$ normals to the planes of symmetry will be axes of rotation-twinning. The same twin-crystal can also be formed by inversion, or by rotation round the axis through a quarter of a circle. The occurrence of such twins in eulytine, tetrahedrite, and diamond has already been described (pp. 231, 233). They are also met with in chalcopyrite. They are illustrated by the stereographic

4 Bk
FIG. 79.



4 Bk P I
FIG. 80.

4 Bk
FIG. 81.



4 Bk P I
FIG. 82.

projections in figs. 79 and 80, and the orthogonal projections in figs. 81 and 82.

These may be taken to represent the reflection-twinning of chalcopyrite in the basal plane, or that of a cubic tetrahedron on the face of the cube. In each there are two other axes of reflection-twinning (AA and $B\bar{B}$). At the same time in the former there are also two axes of rotation-twinning ($D\bar{D}$ and $E\bar{E}$) at right angles to the prism of the first order, and in the latter, six axes of rotation-twinning (four of which are not shown) at right angles to the rhombic-dodecahedron faces.

An axis of contra-directional symmetry when $n/2$ is even, cannot be an axis of rotation-twinning, as it is always a line of symmetry (see p. 228 note, 231, 238 note).

XII. *Axis of* n*-fold contra-directional symmetry where* n/2 *is odd and*

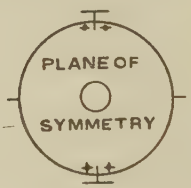
there are n/2 *lines of symmetry at right angles to it, lying in* n 2 *planes of symmetry passing through it.*—Here n must be 2 or 6. The former case is represented by the normal to a plane of symmetry in hemimorphite, 2 Bk, the latter by the principal axis of benitoite, 6 Bk. See figs. 83 and 85.

If the axis of contra-directional symmetry be an axis of rotation-twinning, the $n/2$ lines of symmetry at right angles to it will be axes of reflection-twinning and the $n/2$ normals to the planes of symmetry will be axes of rotation-twinning.

The same twin-crystal can also result from inversion, and where n is 6, by rotation round the axis of contra-directional symmetry through a sixth of a circle. These twins are illustrated in figs. 83 to 86. The twins of hemimorphite on a lateral pinakoid offer an example where n is 2.

An axis of contra-directional symmetry with $n/2$ odd cannot be an

2 Bk
FIG. 83.



2 Bk L I
FIG. 84.

6 Bk
FIG. 85

6 Bk L I
FIG. 86.

axis of reflection-twinning, because it is the normal to a plane of symmetry (see p. 233).

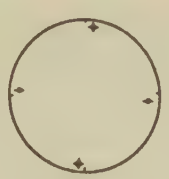
In the absence of planes of symmetry passing through a contra-directional axis, or of lines of symmetry at right angles to it, the fact that the axis of contra-directional symmetry is a twinning-axis, does not involve the occurrence of any other twinning except inversion-twinning and, in the cases specified below, twinning by rotation through an angle less than a half circle. This is illustrated by figs. 87 to 92.

XIII. We have seen that a rotation through a quarter of a circle round an axis of contra-directional fourfold symmetry is a twinning-operation (see p. 239 and figs. 79 to 82 and 91, 92).

XIV. In the same way a rotation through a sixth of a circle round a co-directional axis of threefold or trigonal symmetry, or a contra-directional axis of sixfold or hexagonal symmetry, is also a twinning operation (see pp. 226, 237 note, 240, and figs. 5, 6, 11, 12, 59, 60, 63, 64, 67, 68, 71, 72, 75 to 78, 85, 86, 89, 90).

2 Uk
FIG. 87.

6 Uk
FIG. 89.



4 Uk
FIG. 91.

2 Uk L I
FIG. 86.

6 Uk L I
FIG. 90.

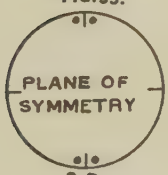
4 Uk P I
FIG. 92.

XV. If a crystal possesses symmetry about a centre, a line of symmetry (that is, an axis with an even symmetry number, see p. 228 note) cannot be a twin-axis. For being a line of symmetry it cannot be an axis of line- or rotation-twinning, and being normal to a plane of symmetry (see p. 233) it cannot be an axis of plane- or reflection-twinning. At the

2 Uc
FIG. 93.

4 Uc
FIG. 94.

6 Uc
FIG. 95.



2 Bc
FIG. 96.

4 Bc
FIG. 97.

6 Bc
FIG. 98.

same time the presence of a centre of symmetry renders point- or inversion-twinning impossible. This is illustrated by figs. 93 to 98. Examples are the crystallographic axes of staurolite, 2 Bc, rutile, 4 Bc, scheelite, 4 Uc, spinel, 4 Bc, pyrite, 2 Bc, and beryl, 6 Bc (Bravais-Miller axes), the ortho-axis of augite, 2 Uc, the vertical axis of apatite, 6 Uc, and lateral axes of calcite, 2 Uc (Bravais-Miller).

Résumé of the explanations of Diagrams and Symbols.

The circle may be regarded as the primitive circle of a stereographic projection in which faces of a crystallographic form of a general type are represented. A plus sign with a dot at its centre indicates an upper face (fig. 1), and a minus sign with a central dot a lower face (fig. 3). As in the gnomonic projection, the projection of a lower face is at the point where the projection of a parallel upper face would be, if it were present. A simple dot without a plus or minus sign indicates the presence of both an upper face and the lower face parallel to it (see fig. 9).

Two short opposite radial lines drawn inwards from the circumference of the circle show the position of a line of symmetry (fig. 16) in the plane of projection. If the plane of projection is a plane of symmetry, the words 'plane of symmetry' are written in the circle (fig. 83). Other elements of symmetry are evident at once from the character and distribution of the projections of the faces.

The left-hand or upper diagram in each case shows the orientation of the untwinned crystal, the other or others, that after the application of a twinning-operation.

Unless otherwise stated, the plane of projection is a twin-plane and its normal the corresponding twin-axis.

Two simple opposite radial lines drawn outwards from the circumference of the circle indicate the position of a twin-axis of rotation-twinning in the plane of projection (fig. 17). Two similar, but shorter lines, each terminating in the centre of a longer line at right angles, show the position in the plane of projection of a twin-axis of reflection-twinning (fig. 18). In the same manner two crosses on the exterior of the circle show the position of a twin-axis of both rotation- and reflection-twinning (fig. 21). A small circle in the centre of the diagram indicates the presence of inversion-twinning (fig. 4).

The same signs, representing the presence of twin-axes in the plane of projection, are also employed in the orthogonal projections.

The number at the commencement of each symbol indicates the number of the times the crystal will coincide with its former position in the course of a complete revolution round the normal to the projection. If the number be 1, the twin-axis is not an axis of symmetry. If the number be 2, it is a twofold or digonal axis, and so on. The only exception is when the symbol concludes with the letter k. In that case half the coincidences are imperfect, equivalent lines being coincident,

but their directions opposed. The normal to the projection may then be described as an axis of contra-directional symmetry of n-fold symmetry when n is the number prefixed. The principal axis of chalcopyrite, for instance, is an axis of contra-directional tetragonal symmetry. The capital letter B following the numeral indicates the presence of one or more planes of symmetry at right angles to the plane of projection, and U the absence of such a plane of symmetry. The small letter c at the end of a symbol denotes the presence of a centre of symmetry; h indicates that, while there is no centre of symmetry, there is a line of symmetry in the plane of projection, and by rotation round this, one termination may be brought into coincidence with the original position of the other. It has already been explained that k indicates that the normal to the plane of projection is an axis of contra-directional symmetry. Here, also, the two terminations are similar, but they are not superposable, unless the axis is parallel to a plane of symmetry.

The small letter u indicates that the terminations of the normal to the plane of projection are unlike.

The different classes of symmetry may be denoted by the same symbols as those of the axis or axes which possess the highest symmetry in each class (this Magazine, 1910, vol. xv, pp. 398–400). The number is then written with Roman numerals, except in the case of the cubic system where the four trigonal axes are employed and the capital letter C is substituted for the numeral.

The capital letter P placed at the end of the symbol indicates that one component has been subjected to a twinning-operation by reflection on the plane of projection; L, that it has been rotated on the normal to the same plane, and I, that it has suffered inversion through the centre (p. 225). The presence of two of these letters shows that the two operations indicated give the same result, and are therefore equivalent to one another. P′ or P″ and L′ or L″ indicate reflection- and rotation-twinning respectively with a twin-axis lying in the plane of projection.

The figures have been executed under my direction by Miss Margaret Reeks, Technical Artist to the Imperial College of Science and Technology, to whom I wish to express my indebtedness.

On changing the plane of a gnomonic or stereographic projection.

By Harold Hilton, M.A., D.Sc.
Professor of Mathematics in Bedford College (University of London).

[Read November 6, 1917.]

§ 1. CONSIDER the poles of the faces of a crystal and the zones (great circles) which join them. Suppose we have given their gnomonic projection on to a certain tangent-plane to the fundamental sphere on which these poles and zones lie. We can find the gnomonic projection on any other plane by aid of the gnomonic net, as explained in this Magazine (1904, vol. xiv, p. 19); and similarly for the stereographic or orthographic projection.

A means of effecting the change of plane when a net is not available was given in this Magazine (1917, vol. xviii, p. 127) for the case of the orthographic projection. Here we give a method which may be employed in the case of the gnomonic projection.

For the orthographic projection we found the new positions of the projections of face-poles and edge-poles when the sphere is rotated about a diameter, the plane of projection being fixed (which amounts to the same as keeping the sphere fixed and altering the plane of projection). This is troublesome for the gnomonic projection, but we may effect our purpose by finding the new positions of the projections of the *zones*; since the projections of face-poles and edge-poles are at once deduced.[1]

In addition to a ruler and set-square we require only a *tangent-scale*. This is a straight-edge marked with degrees, so that the division corresponding to an angle θ is at a distance $r \cdot \tan\theta$ from the zero of the scale; r being the radius of the sphere. Such a tangent-scale is made very quickly out of a strip of squared paper with the help of a table of natural tangents. It may conveniently be divided so as to show every 2°.

[1] For a face-pole is the intersection of two zones, &c. V. Goldschmidt gave a method of finding the *directions* of the new projections in Zeits. Kryst. Min., 1891, vol. xix, p. 352. See also J. W. Evans, this Magazine, 1906, vol. xiv, p. 151.

Suppose then we have the projection of the zones (O being the centre of the projection), and we require the new projection when the sphere has been rotated about the diameter parallel to the line λ through an angle ϕ towards the reader (in fig. 1 $\phi = 70°$). Place the tangent-scale as shown in the figure with its zero at O and its edge μ perpendicular to λ. Draw the lines e, f parallel to λ and at a distance $\frac{1}{2}\phi$ from λ as shown by the tangent-scale. Let the original projection of any zone meet e in B and μ in A. Take D on f so that BD is perpendicular to λ, and C on μ so that AC is ϕ (as measured by the

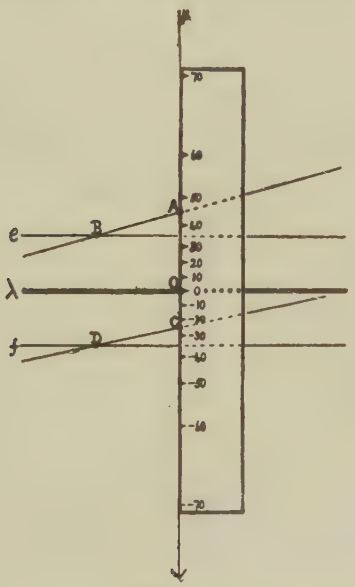


FIG. 1.

tangent-scale). Then CD is the new projection of the zone. The reason is at once clear on considering the gnomonic net. Similarly we can deal with each zone.

A difficulty may arise if A or B is at an inconvenient distance from O. But in practice it will be found that the difficulty is readily surmounted. For instance, suppose A and C on the paper, but B or D too far away. We may find that the original projections of two other zones meet on AB. Then if the new projections of these two zones meet at P, PC is the new projection of AB.

In the last resort the new projection of any point, whose original

projection is R, can be found as follows. Let RH parallel to λ meet μ in H. Take along μ $HJ = \phi$ and $HV = \frac{1}{2}(\phi + 180°)$, as given by the tangent-scale. Then VR meets the line J parallel to λ at the new projection S of R. But this process will seldom be required.

If we take R on AB so that the new projection of RH is at infinity (i.e. $OH = 90° - \phi$, $VO = \frac{1}{2}\phi$), then VR is parallel to CD. This is Goldschmidt's method referred to above.

§ 2. When we have the gnomonic projection of the zones on any plane, the orthographic picture of the crystal on the plane may be drawn.[1] For each edge in the picture of the crystal is perpendicular to the gnomonic projection of the corresponding zone. If we have the orthographic picture on the original plane, we get the orthographic picture on the new plane by forming the new gnomonic projections of the zones (which are perpendicular to the new orthographic pictures of the edges[2]), and noting that the line joining corresponding points in the two orthographic pictures is perpendicular to λ. (See fig. 4, this Magazine, 1917, vol. xviii, p. 128.)

§ 3. The following process is available for changing the plane when the projection is stereographic, instead of gnomonic.

Suppose, as before, the sphere rotated about the diameter λ through an angle ϕ; the plane of projection being kept fixed. Let f be the fundamental circle of the projection, with centre O and radius r. We replace our tangent-scale by a 'tangent-half-scale', i.e. a straight-edge in which the division corresponding to an angle θ is at a distance $r \cdot \tan \frac{1}{2}\theta$ from the zero of the scale (not $r \cdot \tan \theta$, as in § 1). It is placed with its zero at O and its edge along μ perpendicular to λ.

Let e be the zone of the old projection which becomes f in the new; so that e and f have λ as radical axis and cut at an angle ϕ ($\phi = 35°$ in fig. 2). The centre of e is on μ at a distance $r \cdot \tan \phi$ from O (2ϕ as shown by the scale). Let V be the centre of the circle coaxial with e and f, and bisecting the angle between them. The distance VO is $r \cdot \tan \frac{1}{2}\phi$ (ϕ as shown by the scale). The point V is the projection of the pole of the zone whose projection is e.

Suppose now that the original projection of any zone meets μ at A and e at B. Make $AC = \phi$, as shown by the scale, and let VB cut f at D. Then the new projection of the zone passes through C, D and has

[1] That is, the picture of the crystal as seen by an eye at a considerable distance in the normal to the plane.

[2] The *directions* of the new projections of the zones are sufficient for drawing the picture of the crystal. See Goldschmidt, loc. cit.

its centre on the line through O perpendicular to OD. Hence it is readily drawn.

§ 4. If we require merely the orthographic picture of the crystal on the new plane of projection, it is unnecessary to draw completely the new projections of the zones. In fact, the picture of the edge corresponding to the zone CD is perpendicular to OD. Hence all we require

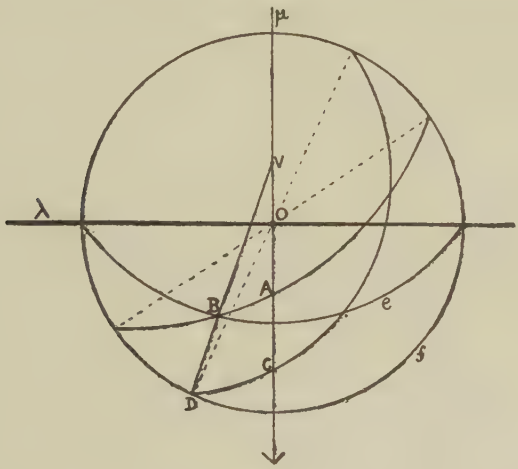


Fig. 2.

is the position of D; and we need not concern ourselves with the points A and C.

This process has a considerable analogy with Goldschmidt's method for the gnomonic projection, as the reader will readily see, on comparing his paper with the author's 'Mathematical Crystallography', 1903, chap. i, § 5.

On cleavage-angle in a random section of a crystal.

By Harold Hilton, M.A., D.Sc.
Professor of Mathematics in Bedford College (University of London).

[Read November 6, 1917.]

§ 1. SUPPOSE a crystal has two good cleavages, and that a thin section is cut in a random direction. Cleavage-cracks are seen in the section which consist of two sets of parallel lines inclined at an acute angle ϕ, which may have any value whatever, depending on the direction in which the section is cut. The question suggests itself: what is the chance that ϕ may lie between assigned limits? This question proves to be incapable of a direct mathematical solution, but it can be solved graphically. This is worked out here for two typical cases, and the general method of performing the graphical solution in every case is indicated.

§ 2. Suppose that a sphere is taken, and that the radii of the sphere perpendicular to the cleavage-planes meet the sphere in A and B. Let O be the pole of the great circle AB. Suppose that the radius perpendicular to the plane of the random section meets the sphere in P. It is readily seen that the acute angle ϕ between the cleavage-cracks is the acute angle between the great circles PA and PB. If $\phi = \alpha$, P traces out a curve on the sphere. The ratio of the area enclosed by this curve to the area of the sphere is the chance that the angle in a random section should be $\leq \alpha$.

To find the curves, suppose $AB = 2\beta$, $OP = \rho$, and that OP makes an angle θ with the bisector of the angle AOB. Then from the triangles OPA, OPB, APB

$$\cos AP = \sin\rho \,.\, \cos(\beta - \theta), \qquad \cos BP = \sin\rho \,.\, \cos(\beta + \theta),$$
$$\cos 2\beta = \cos AP \,.\, \cos BP \pm \sin AP \,.\, \sin BP \,.\, \cos\alpha.$$

Eliminating AP, BP, we have

$$\{\cos 2\beta - \cos 2\theta + 2\cos 2\beta \,.\, \cot^2\rho\}^2 = 4\sin^2 2\beta \,.\, \cot^2\alpha\,(1 + \cot^2\rho)$$

and

$$2\cos 2\beta \,.\, \operatorname{cosec}^2\rho \pm 2\sin 2\beta \,.\, \cot\alpha \,.\, \operatorname{cosec}\rho - (\cos 2\beta + \cos 2\theta) = 0.$$

Assigning different values to θ we get the corresponding values of cot ρ or cosec ρ, and thus trace the curves.

In figs. 1 and 2 we map the curves for the cases $2\beta = 90°$ and $2\beta = 60°$, which we shall call respectively the 'augite' and 'hornblende' cases. The plane map is drawn so that the polar co-ordinates of P are $(\sin \frac{1}{2}\rho,\ \theta)$. This mapping causes considerable distortion in the curves, but secures the equality of corresponding areas on the sphere and the map.

In fig. 1 we have $2\beta = 90°$. The curves corresponding to the following values of α are shown in order as we go out from O horizontally and vertically: $\alpha = 90°$ (the lines OA and OB), $\alpha = 76°$ ($\tan^{-1}4 = 75° 58'$), $\alpha = 60°$, $\alpha = 45°$, $\alpha = 30°$, $\alpha = 0°$ (a circle with centre O).

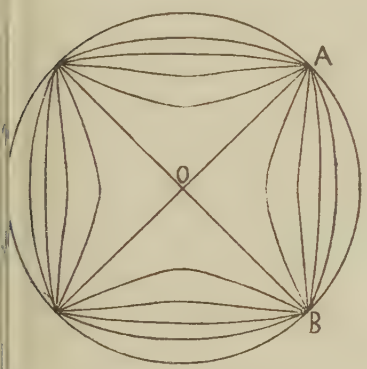


FIG. 1.—$2\beta = 90°$.

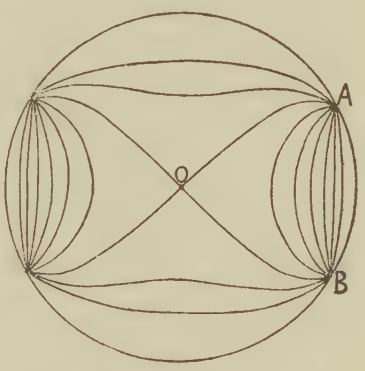


FIG. 2.—$2\beta = 60°$.

In fig. 2 we have $2\beta = 60°$. As we go out from O horizontally we have $\alpha = 60°$ (passing through O), $\alpha = 76°$, $\alpha = 90°$ (touching OA, OB at A and B), $\alpha = 76°$, $\alpha = 60°$, $\alpha = 45°$, $\alpha = 30°$, $\alpha = 0°$ (a circle). As we go out from O vertically we have $\alpha = 60°$, $\alpha = 45°$, $\alpha = 30°$, $\alpha = 0°$.

§ 3. Measuring the area enclosed by any one of these curves (drawn on squared millimetre paper, and the squares counted), we get fig. 3, in which is shown the chance p that the cleavage-crack angle ϕ for a given random section should be $\leq \alpha$. The broken line refers to the hornblende case and the continuous line to the augite. The horizontal scale shows the value of α (every 10°) and the vertical scale the value of p (every 0·1). From the figure may be read off any information we require. For instance, the chance that ϕ lies between 50° and 70° is about 0·36 and 0·21 in the hornblende and augite cases respectively.

§ 4. In fig. 4 we show the slope (the tangent of the angle which the tangent makes with the horizontal) of the two curves of fig. 3. The broken and continuous lines refer to the hornblende and augite cases respectively; the horizontal scale shows α (every 10°) and the vertical scale the slope (every unit).

Suppose that in a rock-section a mineral is known to be either hornblende or augite, the a priori probabilities of the two cases being estimated as in the ratio $\lambda : \mu$ before the cleavage-crack angle ϕ is measured. Suppose now that ϕ is measured and found to be equal to α. Measure the ordinates in fig. 4 corresponding to the abscissa α. If these are y_1 and y_2, the chance that the mineral is hornblende is

$$\lambda y_1 \div (\lambda y_1 + \mu y_2).$$

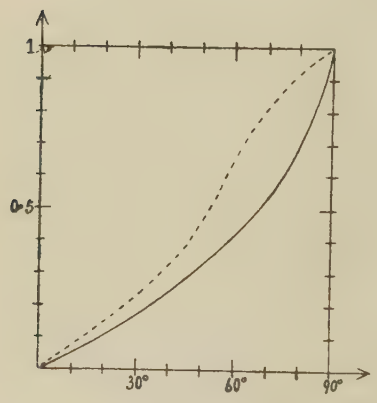


Fig. 3.

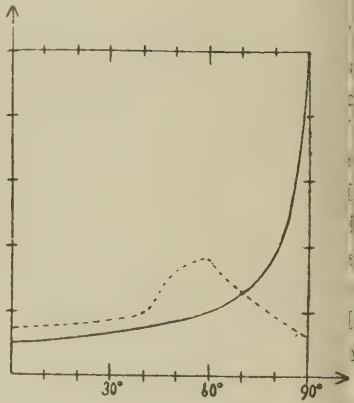


Fig. 4.

For instance, suppose that a priori the mineral is equally likely to be hornblende or augite. If ϕ is nearly 90°, there are long odds (about 8 to 1) in favour of the mineral being augite. If ϕ is 60°, there are odds of about 7 to 4 in favour of its being hornblende. If ϕ is 70°, it is about an even chance that the mineral is hornblende or augite. (In reality ϕ is a little less than this, as the values of 2β in the case of augite and hornblende are 87° 12′ and 55° 49′, not 90° and 60° as have been taken for convenience of calculation. But the above is probably near enough for all practical purposes.)

§ 5. A similar problem is the following: a section of a crystal is taken of given small thickness in a random direction. The birefringence for parallel light normal to the section (as shown by the interference

tint) is a fraction k of the maximum possible birefringence; i.e. that in which the plane of the plate contains the optic axes. What is the chance that $k \leq m$, where m is given?

If the optic axes are the radii of the sphere through A and B, the plane is perpendicular to the radius through P, and the birefringence is a fraction m of the maximum,

$$\cos AP = \sin\rho \,.\, \cos(\beta - \theta), \qquad \cos BP = \sin\rho \,.\, \cos(\beta + \theta),$$
$$\sin AP \,.\, \sin BP = m;$$

provided that the maximum birefringence is not too large.

Then eliminating AP and BP as before, P lies on a curve whose equation is

$$\cos^2\rho\,(\cos 2\beta + \cos 2\theta)^2$$
$$= -(\sin^2 2\beta + \sin^2 2\theta) + 2\{\sin^2 2\beta \,.\, \sin^2 2\theta + m^2(\cos 2\beta + \cos 2\theta)^2\}^{\frac{1}{2}}.$$

The curves for various values of m and 2β may be mapped as before. The chance that $k \leq m$ is the ratio of the area enclosed by the corresponding curve to the area of the sphere.

We leave the graphical solution to the reader. In two cases the ratio of the areas is obtainable without recourse to graphical methods.

In a uniaxial crystal the birefringence is $\sin^2\omega$ times the maximum, ω being the angle between the optic axis and the normal to the section. Hence the chance that the birefringence is $\geq m$ times the maximum is $(1-m)^{\frac{1}{2}}$.

If the optic axes are perpendicular ($2\beta = 90°$), and $m = \frac{1}{2}$, the ratio of the areas is

$$2\tan^{-1}\frac{10\sqrt{2}}{23} \div \pi, \text{ i.e. about } 0{\cdot}35.$$

Thus the chance that the birefringence is $\geq$ half the maximum when a random section of given thickness is taken in a crystal (i) which is uniaxial, (ii) which has perpendicular optic axes, is respectively 0·71 and 0·65. For any other crystal the chance will lie between these two quantities.

Lattice-like inclusions in Calcite from North Burgess, Ontario.

(*With Plates VIII–X.*)

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THE pale celestite-blue calcite which occurs on the eastern half of Lot 13, Range V, of North Burgess township, Lanark county Ontario, contains very remarkable lattice-like inclusions of a hydrous magnesium silicate.

The calcite forms crystalline masses belonging to the Grenville series which has a very extensive areal development in certain parts of Ontario. The texture varies from medium to very coarse, in which the individual cleavage-rhombs of calcite measure one inch or more in diameter. Repeated twinning on e $(01\bar{1}2)$ or (101) is almost invariably exhibited, and is especially pronounced in the more coarsely crystallized varieties. Both the twinning and the crystalline character are results of the very intense metamorphism to which this Archaean limestone has been subjected.

The inclusions described below were first observed in a coarsely crystallized specimen in the McGill University collection; subsequently the Geological Survey kindly presented several larger specimens, which rendered possible a more detailed examination and analysis of this material.

In these specimens, owing to the secondary twinning, each cleavage face of the calcite is traversed by three sets of twin-lamellae or striae which are somewhat evenly spaced from one to two millimetres apart; a large rhombohedron-face is thereby subdivided by fine striae into a number of small rhombs, which are themselves intersected by the more prominent twin-lamellae following the direction of their longer diagonals.

On examination, it was observed that the calcite is penetrated by extremely fine, white needles. Owing to the colour and cloudiness of the crystals, the presence of these needles is not very noticeable by casual inspection of the specimens, but with a lens they can be clearly seen for some depth within the calcite, and their regular orientation is at once evident. The needles follow three directions, which are related to the calcite crystal in such a way that they correspond to the edges of the rhombohedron e $(01\bar{1}2)$, and they thus lie in three planes, which would truncate the terminal edges of the cleavage rhombohedron. Moreover, the needles invariably emerge from the cleavage-faces at points of intersection of the fine lines formed by the repeated twinning already referred to. These features are illustrated diagrammatically in Plate X, fig. 1, which represents a cleavage rhombohedron of the calcite viewed normally to one of its faces.

By treatment with cold dilute hydrochloric or nitric acid, the calcite is readily dissolved, but the needles, being practically insoluble, remain as a scaffolding or lattice having the angles and form of the negative obtuse rhombohedron e $(01\bar{1}2)$. If care is taken to avoid excessive effervescence, as well as movement of the specimen, during solution, it is possible to obtain an unbroken and continuous lattice from cleavage-pieces an inch or more in diameter. The lattices are sufficiently strong to permit of their being moved about in the solution, and the smaller ones may even be transferred with safety from one vessel to another, provided they are kept completely immersed; but they immediately collapse when an attempt is made to remove them from the solution or water. It is unfortunately not possible to obtain a very satisfactory photograph of these beautifully delicate structures when they are at all large; the needles being so close together that those in successive planes interfere and overlap to give the network a false appearance of solidity. Some examples of smaller ones, however, are shown in Plates VIII and IX. For these photographs, which illustrate very clearly the characteristic features and general appearance of the structures, the writer is indebted to Mr. S. Werner, of the Metallurgical Department.

The orientation of the lattice within the cleavage rhombohedron of calcite is shown diagrammatically in Plate X, fig. 2; this figure also illustrates the way in which the needles emerge at points lying along lines parallel to each of the rhombohedron-edges, and also parallel to the longer diagonal of each face, as well as the fact that the planes in which the needles lie would truncate the terminal edges of the cleavage rhombohedron, and coincide with the planes of the obtuse negative

rhombohedron e (01$\bar{1}$2). To avoid complication, the secondary twinning is omitted in this figure.

The fact that the needles build up a lattice which has the form of the rhombohedron e (01$\bar{1}$2), and also that the skeletal planes of the structure are invariably coincident with the planes of the twin-lamellae within the calcite, indicate at once a close connexion between the development of the twinning and of the enclosed needles. Evidently the secondary twinning preceded the formation of the needles, although not necessarily by any long time interval; indeed, the two may well have had an essentially contemporaneous origin. The twinning is not only repeated, but it has taken place on three mutually inclined planes, whose intersections correspond with the directions of the edges of the rhombohedron e (01$\bar{1}$2). This secondary twinning has been imposed upon the crystalline limestone as a result of the extreme pressure to which it was subjected during its metamorphism. Under these conditions, capillary pressure channels, if formed at all, would be expected to develop at the intersections of the inclined twin-planes; every line of intersection of the thin lamellae, in reversed position, might well constitute a line of extreme disturbance and weakness in the calcite, and it is along these lines that the needles have developed.

Thus the occurrence is not to be regarded as a regular intergrowth in the proper sense of the term, since the needles have been deposited along capillary channels[1] whose positions within the calcite were pre-determined by the secondary twinning: the resulting lattice does not owe its form to any crystallographic similarity between its material and that of the calcite, but is in reality pseudomorphous.

The needles are extremely thin; an idea of their dimensions, and also of their relative and rather uniform spacing within the lattice, may best be gained from Plate VIII, in which the specimens are shown magnified $4\frac{1}{4}$ diameters. The needles are pure white, with a dull lustre, though both these features may be due to the etching of the surface by the dilute acid. Two surfaces, opposite to one another, frequently have a feeble vitreous lustre, as though the needles were platy; some examined in cross section were found to be four-sided or polygonal. They are quite soft, non-flexible, and brittle. The specific gravity is in the neighbourhood of 2·5; the material floats on a liquid of specific gravity 2·6, and sinks when this is lowered to 2·45, but owing to the minute

[1] These were studied by Sir David Brewster in 1844, and described in greater detail by G. Rose, Über die im Kalkspath vorkommenden hohlen Canäle, Abhandl. Akad. Berlin, for 1868, 1869, 57–79.

size of the needles a more exact determination was not possible. Heated before the blowpipe, the needles are fusible.

The needles do not exhibit very definite optical characters. Immersed in oil and examined under the microscope, they appear drusy and do not transmit much light; they have straight extinction, weak or medium birefringence, and compensation takes place when the quartz-wedge is inserted normal to their length. In thin sections of the calcite itself, the needles are scarcely noticeable. Fine, but indistinct, lines may be seen traversing the calcite crystals, but except that they follow different directions, they can hardly be distinguished from the usual cleavage-traces and twin-lamellae.

In order to obtain material for analysis, a quantity of the calcite was dissolved in dilute hydrochloric acid, and the residue washed. From this a preliminary separation of the white needles from the insoluble minerals present was made by repeatedly agitating the mixture in a beaker full of water and filtering off the needles which, largely owing to their habit and small size, remained in suspension after the other minerals had sunk to the bottom. This material was dried at 100° C., after which the needles were separated as cleanly as possible from admixed minerals (for the most part minute flakes of graphite) by picking the latter out under the microscope.

Two separately-prepared samples gave the results shown in columns I and II below. The quantity of material used was in each case very small (0·0821 and 0·2987 grams respectively). The 10·78 per cent. H_2O given in analysis II represents the loss in weight on ignition. The FeO shown in the analyses is the total iron calculated as ferrous oxide.

	I.	II.	Calculated for 5 MgO . 6 SiO_2 . 4 H_2O.
SiO_2 ...	57·23	56·37	56·96
MgO ...	30·35	30·43	31·65
FeO ...	1·66	2·47	—
CaO ...	0·37	none	—
H_2O ...	Not detd.	10·87	11·39

The material is not entirely unacted on by hydrochloric acid. A small quantity was digested with concentrated acid for some time, and the residue, after washing and drying at 100° C., was found to contain SiO_2 63·93, MgO 26·16, FeO 1·21, H_2O 8·08 per cent. It is thus possible that the analyses given in columns I and II above may not

express the true composition of the needles, which were no doubt affected in some slight degree by the cold dilute acid in which the calcite enclosing them was dissolved. However, the material used in each analysis was the product of a separate preparation, and from the close correspondence in the results obtained it may be concluded that the essential composition is approximately as given.

The needles are thus a hydrous magnesium silicate, and in composition they may be nearly related to certain varieties of serpentine or talc. The figures actually obtained in the analyses agree most nearly with the formula $5\,MgO\,.\,6\,SiO_2\,.\,4\,H_2O$, which is that usually assigned to spadaite; the last column gives the theoretical composition for this compound.

The minerals left undissolved when the calcite is treated with cold dilute acid include pyroxene and quartz, both of which usually have the form of small, colourless, transparent grains, sometimes almost perfectly spherical, and at other times exhibiting bright faces with rounded edges. Titanite of a clove-brown colour is less common; it also is usually lenticular, but occasionally occurs as well-developed crystals. Graphite is fairly plentiful, as thin hexagonal plates, whose edges in many cases are modified by narrow facets which yield bright reflections; measurement showed that in most cases these belong to the rhombohedron $-(10\bar{1}1)$, but other forms are probably also present. Pyrite is not common, and the majority of the crystals observed have the normal habit and are rich in forms. More interesting are some extremely thin capillary crystals of this mineral, a few only of which were found when picking out the material for analysis; one has a length of 2 mm., but for the most part they are much shorter than this. These crystals are bright, with perfect faces and sharp edges; they are elongated in the direction of an octahedron edge, and are doubly terminated. The forms present were identified by partial measurement of two or three of the crystals. The principal form in the 'prism' zone is the octahedron, and the edges between its four faces are replaced by very narrow facets belonging to the cube, rhombic-dodecahedron, and trapezohedron $n\,(211)$. These are all well defined on the crystals measured, and readings by maximum illumination indicated, in addition, the presence on some of the crystals of faces belonging to the forms $m\,(311)$, $p\,(221)$, $q\,(331)$, and $r\,(332)$. The elongation of pyrite crystals in the direction of an octahedron edge, instead of along a cubic axis, is apparently unusual.

The crystals of these included minerals are all small, seldom more than 1 or 2 mm. in diameter. They were all formed prior to the needles of hydrous magnesium silicate. The minute flakes of graphite are

frequently seen to be caught up and held in the lattice, but not penetrated by the needles; and the same is no doubt true of the other minerals also, but owing to their weight they break away from the fragile structure when the calcite supporting them is removed by solution.

With regard to the source of the solutions which have supplied the magnesium silicate of which the needles are composed, several alternative hypotheses might be advanced. The blue calcite itself contains little or no magnesium; an analysis gave CaO 56·12, MgO 0·41, and CO_2 43·53 per cent., the last constituent being estimated from the loss in weight on ignition. It is quite possible, however, that the original limestone may have contained some magnesium, and that this was set free, and rendered available in the form of a solution of magnesium silicate, during the metamorphism of the limestone, when it acquired its crystalline character and the secondary twinning was imposed upon it. The possibility of such a source receives support if, as has been suggested, the needles were formed contemporaneously with, or immediately after, the development of the twin-lamellae.

On the other hand, the alteration of magnesian silicates contained in the crystalline limestone might have provided the necessary solutions. It may be recalled that serpentine is found in the Grenville limestone in many parts of Ontario as well as in Quebec and elsewhere, disseminated through the rock in the form of rounded grains, and usually in small amount only. Adams and Barlow[1] have shown that there is every reason to believe that this serpentine has been derived from the alteration of the grains of pyroxene which are so abundant in some of these limestones. In other cases, the serpentine has clearly resulted from the alteration of chondrodite, and of olivine or forsterite. In all these occurrences, the serpentine retains the form of the parent mineral, and there has been little or no transportation of material, such as has evidently taken place in the case of the needles under consideration. As stated above, pyroxene, in small rounded crystals, is distributed rather plentifully through the blue crystalline limestone of North Burgess township; so far as observed, however, this pyroxene is quite clear and fresh, with no accompanying serpentine, and there is no evidence to suggest that it has been in any way responsible for the magnesium silicate of the lattice-like structures.

[1] F. D. Adams and A. E. Barlow, Geology of the Haliburton and Bancroft areas, Province of Ontario. Geological Survey of Canada, Memoir No. 6, 1910, p. 213.

The cause of the celestite-blue colour of the calcite was not ascertained; it may, in part at least, be due to the great number of minute inclusions.

Explanation of Plates VIII–X.

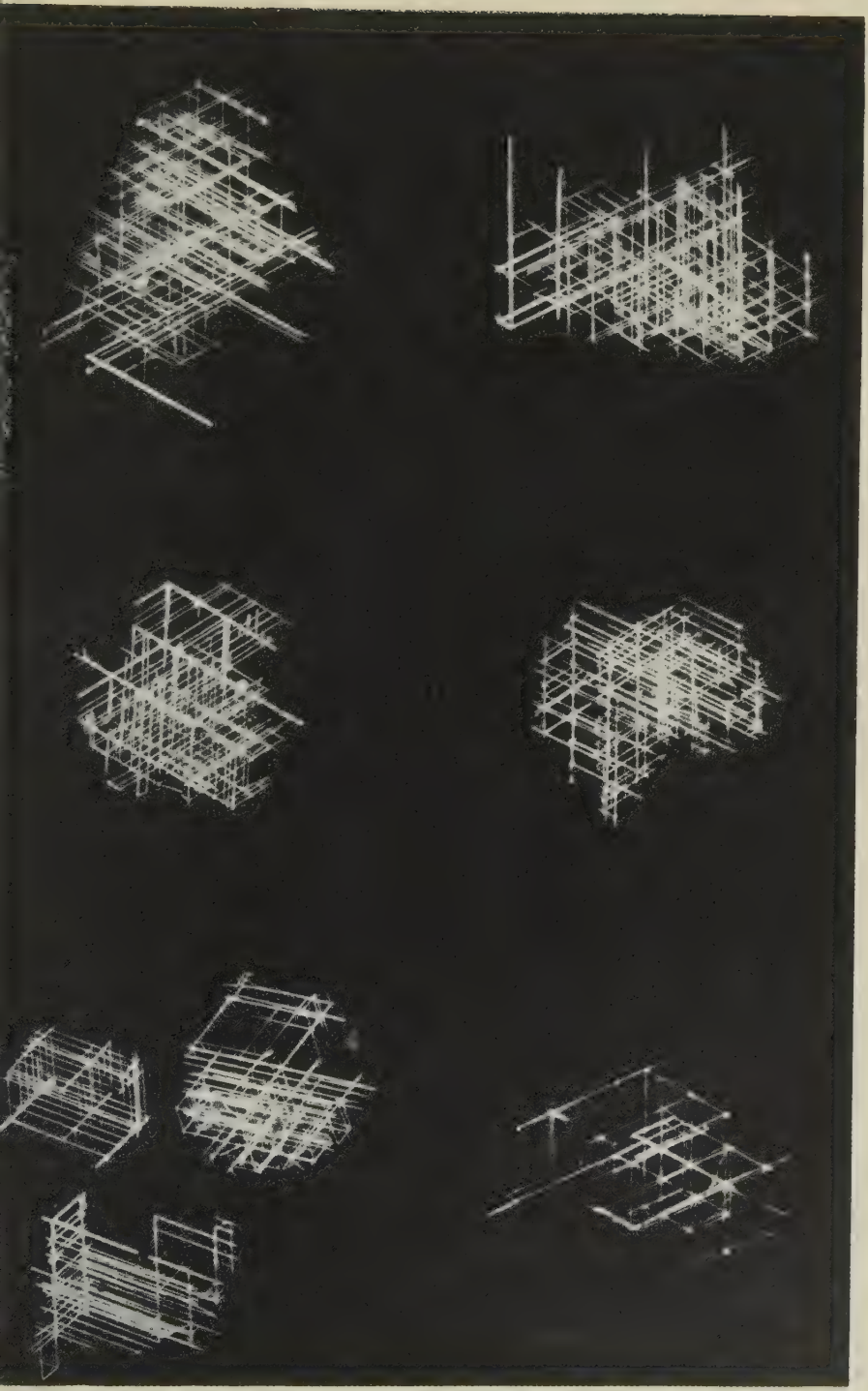
Plate VIII.—Photographs of delicate lattice-like structures, consisting of hydrous magnesium silicate, isolated by dissolving the enclosing calcite in acid. ($\times 4\frac{1}{4}$.)

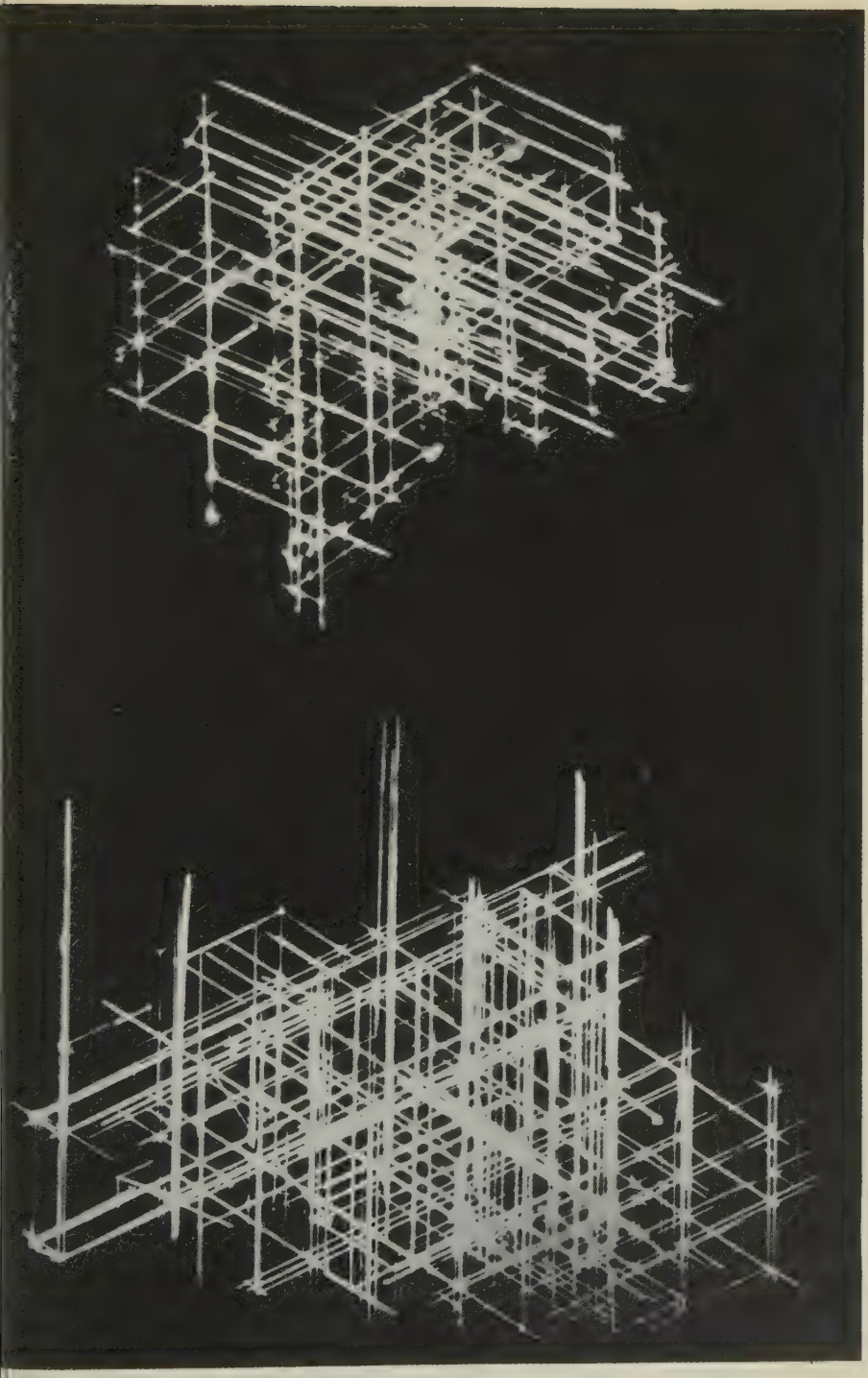
Plate IX.—The same. ($\times 10$.)

Plate X.—Diagrammatic representation of the same.

Fig. 1.—Cleavage rhombohedron of calcite, viewed normally to one face, showing striae due to lamellar twinning parallel to the three faces of the obtuse negative rhombohedron *e*. The enclosed needles emerge from the faces at the points of intersection of these twin-striae.

Fig. 2.—Cleavage rhombohedron of calcite showing orientation of the enclosed lattice. The needles are in there directions parallel to the edges of the obtuse negative rhombohedron *e*. (See p. 253.)





R. P. D. Graham: Lattice-like Inclusions in Calcite. (× 10.)

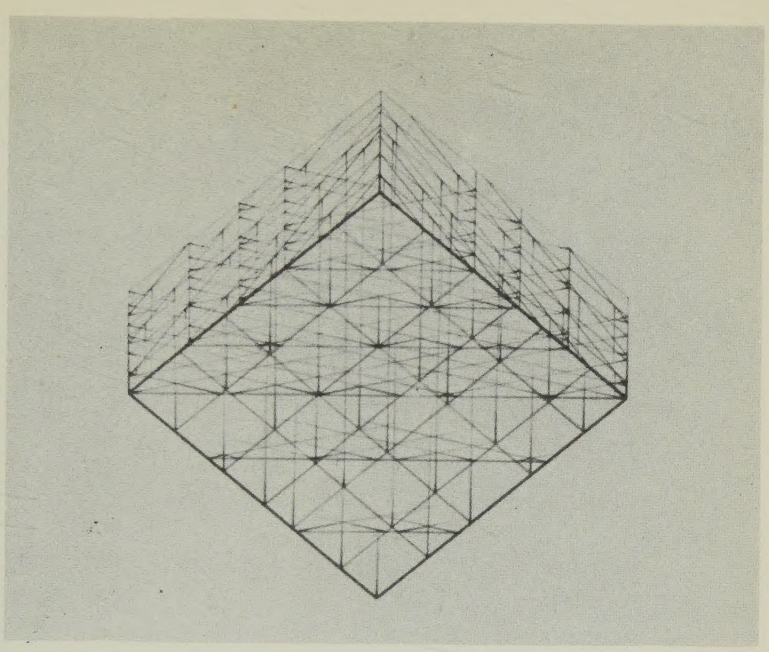


Fig. 1.

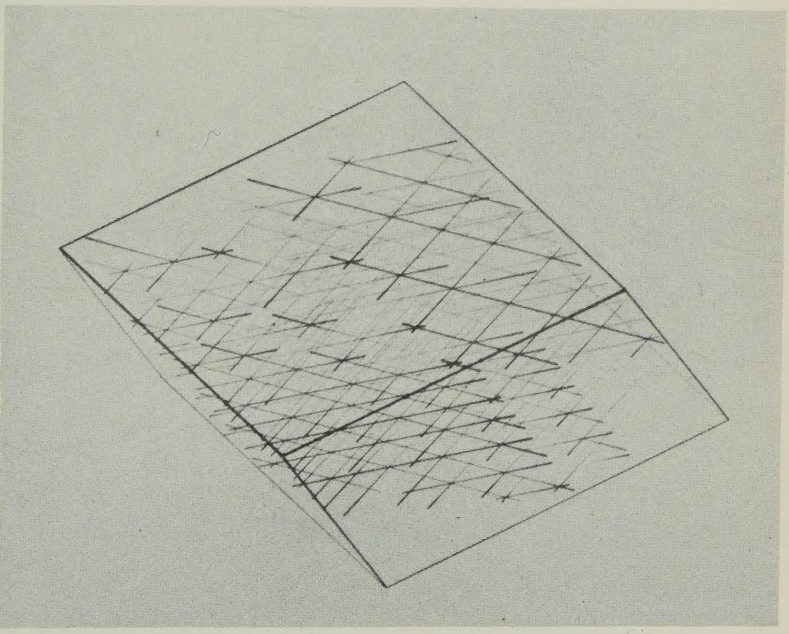


Fig. 2.

R. P. D. Graham: Lattice-like Inclusions in Calcite.